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Factors Affecting the Sprouting Response of Woody Caatinga Species and Their Implications for Improved Caatinga Management

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FACTORS AFFECTING THE SPROUTING RESPONSE OF WOODY CAATINGA SPECIES AND THEIR IMPLICATIONS FOR IMPROVED CAATINGA MANAGEMENT

by

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This work is dedicated to the rural people of northeast Brazil and to their counterparts throughout the world, in the hopes that in some way, it will improve their lives.

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In northeast Brazil grazing is a major use of much of the semi-arid woodlands (caatinga). Animal production is limited by lack of dry season forage, primarily deciduous tree leaves. Management is constrained by the persistence of undesirable trees that sprout from the stump (coppice). This study evaluates the possiblity of manipulating coppicing trees to improve caatinga management, particularly dry season forage production.

The season of cutting can influence coppicing. Trees were cut early and late in the wet and dry seasons. After two years, trees of all species cut in the late wet season produced less biomass than those cut in other seasons. Production of most species was maximized by cutting in the dry season. Desirable species should be cut during the dry season to maximize production and less desirable ones in the

late rainy season to reduce coppicing. Seasonal cutting does not cause mortality, nor can it cause any prolonged change in the leaf:stem ratio.

Another study quantifies the response to defoliation of coppice growth by goat browsing or manual removal. The palatable browse species sabiá and catingueira suffered no mortality while less palatable species experienced significant mortality. One year after defoliation, defoliated trees still produced less biomass than non-defoliated trees. Browsed stumps sprouted again during the dry season.

Changes in the abscission phenology of coppice growth were observed. Coppice growth retained leaves from 2 to 12 weeks longer than intact trees of the same species. Regrowth on browsed stumps remained green for the duration of the 5 month dry season. Delaying abscission regulates the availability of dry season forage, and has implications for animal production that merit further investigation.

Coppice growth can be manipulated to change the species composition of the regenerating stand, improve seasonal forage balance, and reduce site disturbance. Changing from even-aged to uneven-aged management might facilitate these changes. Prospects for improving wood production are better than animal production because of the limits imposed by mixed production systems, land tenure, and human population growth.

(117 pages)

CHAPTER I

INTRODUCTION AND BACKGROUND

Semi-arid Shrub/Woodland Ranges

Woody plants cover more than half the earth's land area (Box 1972). Although trees and shrubs of various species are distributed over a wide range of climatic conditions, they are admirably suited to arid lands. Perennial plants use water, energy, and nutrients efficiently. Plants with permanent woody stems commit fewer resources to annual regeneration, leaving a larger proportion available for photosynthesis and reproduction. Woody plants may create favorable conditions for the growth of other plants: their roots and litter enrich and stabilize the soil, their branches provide shelter from hot sun and physical damage, and they pump nutrients from deep within the soil and release them on the surface during decomposition (McKell 1975). Deep or spreading root systems maximize water uptake. Woody plants can survive stressful periods using stored reserves, continuing to occupy the site, thereby protecting the soil and providing fodder during drought.

Shrublands and woodlands constitute a valuable resource (Gonzales 1972, Lundholm 1976, McKell 1975). As forage, browse contains energy and nutrients needed by grazing animals, and is frequently high in crude protein (Cook 1972). Pastoralism is often the only economically and ecologically sound way to exploit these lands. Their relatively low productivity and remote location do not justify intensive development, but pressures exerted by the world's expanding human population and growing agricultural constraints increase the importance of animal production from these areas.

Woody plants have other uses in addition to forage. Woodlands are an important source of construction timber, posts, and thatch, as well as fuelwood, a commodity increasingly in demand worldwide. Many woody plants produce foodstuffs, waxes, resins, gums, and medicinal compounds valued by local residents and importers worldwide. Thus multipurpose use of woodlands is the rule.

The traditional uses of these regions are rarely damaging until population pressure and the application of technologies developed for more forgiving temperate ecosystems magnify the impact of humans to the point of seriously threatening productivity (Cloudsley-Thompson 1970, Sherbrooke and Paylore 1973). The current situation in the shrub-woodlands (caatingas) of northeast Brazil is typical of semi-arid tropical woodlands and shrublands worldwide (figure 1).

Small Ruminant Production in the Caatinga

Annual rainfall in the interior of northeast Brazil is only 300-700 mm/yr, concentrated between January and April and followed by a long dry season. Prolonged droughts occur frequently. Temperatures are uniformly hot and the caatinga vegetation is a thorny tangle of leguminous trees and shrubs mixed with cacti and succulents.

Agriculture is the primary industry of this region. Although 70 percent of the agricultural income is from cultivated crops, crop production is notoriously unreliable because of erratic precipitation (Robock 1963). Grazing of livestock, which are an important source of food and income, is the only major use of much of the caatinga. Sheep and goats are the most common livestock, accounting for 18 and 92 percent, respectively, of the nation's sheep and goat populations (USAID 1980).

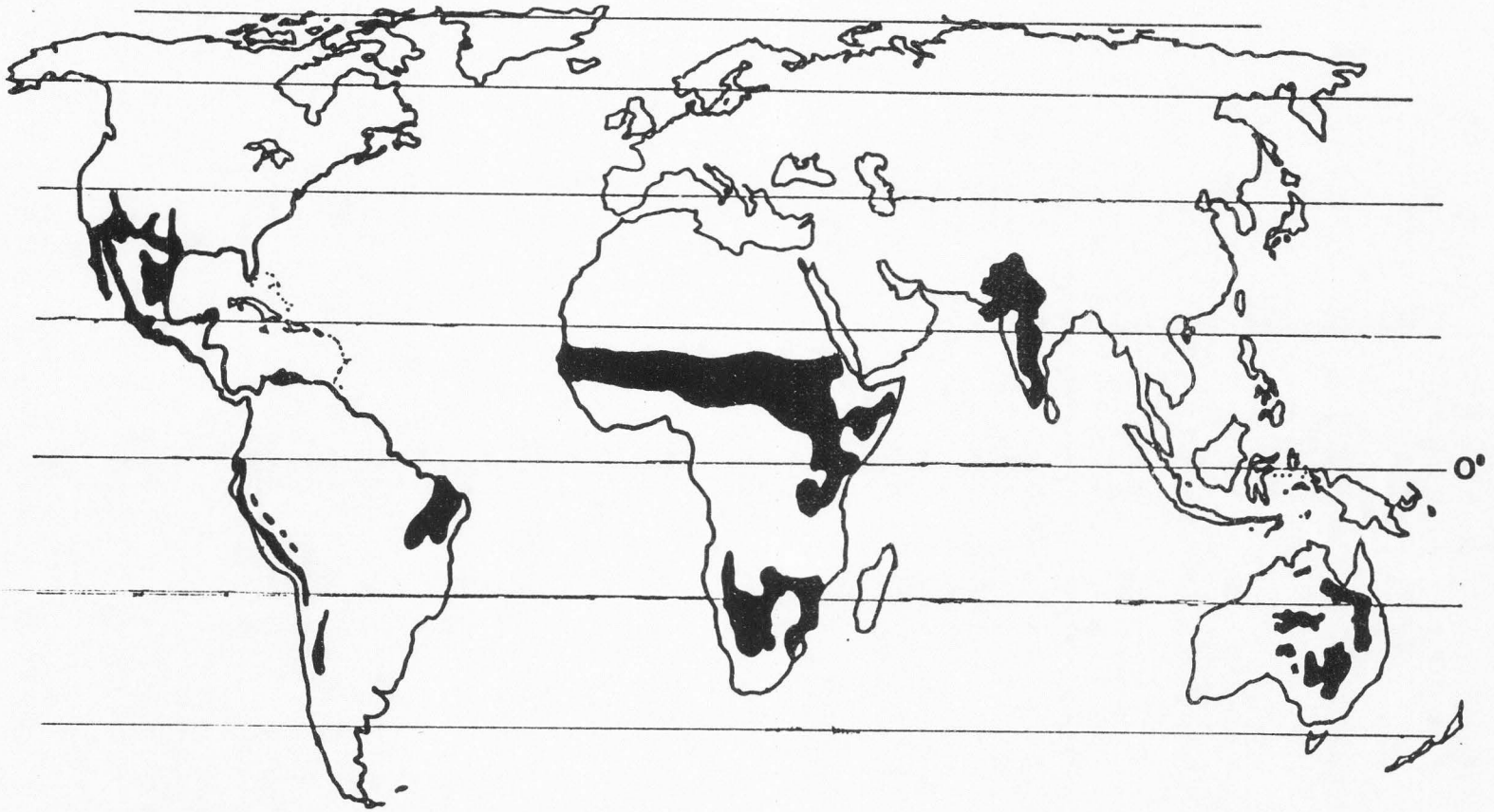

Figure 1. Distribution of semi-arid shrub/woodland ranges analogous to the Brazilian caatinga.

Generally, sheep and goats roam unsupervised in the caatinga during the day and are penned at night. Often, water is available only at the pen or when animals are herded to small, seasonal reservoirs. In the dry season, sheep diets may be supplemented with crop residues: corn silage; chopped, spineless Opuntia; cut Pennisetum; or rarely, grain. These resources are allocated first to cattle, if present, and then to sheep, but are rarely provided to goats, the least valuable livestock. Most dry season forage comes from the caatinga in the form of dried leaves from the trees and shrubs. Most small ruminants are owned by small scale farmers who own little or none of the range their animals use. Their status as sharecroppers or communal users of unimproved rangeland seriously limits their motivation and financial ability to improve the range. Also, although crop and livestock production are closely integrated, the need to protect crops from livestock (especially goats) limits management options. One avenue for improving small ruminant production is developing appropriate techniques for improved use and management of the caatinga. It is assumed this will contribute to improved welfare of the small scale farmer.

The rural northeast is densely populated with people at or below the subsistence level. As part of an effort to improve the well-being of these people, the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) is participating in a collaborative small ruminant research program with the U.S. Agency for International Development and several U.S. land-grant universities. Headquartered at the Centro National de Pesquisa de Caprinos (CNPC) near Sobral, Cearà, this program addresses all aspects of small ruminant production, including range management.

As the lead institution for the range management program, Utah State University's Range Science Department has identified four technical objectives:

1. Ecological inventory and assessment.
2. Forage plant introduction and evaluation.
3. Brush control and manipulation.
4. Range animal nutrition. (Malechek 1980)

This work relates to the brush control and manipulation objective.

The Brush Problem

Brush is the term used to describe shrubs and small trees that are undesirable because they interfere with a preferred land use (Kothmann 1974). For the stockman, brush is a problem when it impacts forage production, forage quality, or access to forage.

Forage production is ultimately limited by net primary production. Primary production is a function of the availability of light, water, nutrients, and heat, any of which in short supply relative to the others, limits productivity. Net primary productivity is the dry matter that remains after plant respiration, and is measured as biomass. Shrublands and woodlands are not as productive as some other ecosystems. Their productivity ranges from 250-1200 $g/m^2/yr$ (Whittaker et al. 1973, cited in Whittaker 1975). Some of the adaptations allowing woody plants to survive stressful periods may also limit their productivity in favorable times. Only a small portion of the net primary productivity of a system is available to herbivores, and even less to secondary consumers. Energy lost in conversion limits the efficiency of energy transfer between trophic levels to less than

10 percent; thus, when net primary productivity is low and a decreasing portion of it is available at each succeeding trophic level, potential protein production for human use is very low. Yet, there is often no other means of using arid lands for food production. Therefore, maximizing forage production is necessary to increase the ability of arid lands to support humans. Brush competes with forage plants. The tree's or shrub's efficient use of water, nutrients, and space enables it to dominate sites where other species may be more desirable for livestock production.

Forage quality depends on the type of forage needed, the plant's protein, nutrient, fiber, and water content as well as its palatability and digestibility. Each animal prefers different forages, both different species and different plant parts. These preferences vary with the condition and needs of the animal, the growth stage of the plant, and the selection of forage available. For example, sheep may require browse for winter feed and lush herbage before breeding. A brush species on cattle range may be valuable forage on sheep range. The influence of brush on forage quality is a complex matter.

Access to forage is affected when thick, and possibly thorny brush restricts the movements of people and animals, making livestock management difficult. Shrubs and trees hide predators and provide habitat for pests such as tsetse and ticks. Tall browse species grow out of reach of livestock, and low growing species conceal otherwise usable understory vegetation. Woody material decomposes slowly, thus even dead plants can be an obstacle. Brush limits the use of machinery, and persistent debris and rapid regrowth of disturbed vegetation can make range improvement difficult to achieve.

The Brush Problem in the Caatinga

In northeast Brazil, fluctuating forage supplies are a major constraint on small ruminant production. Most sheep and goats graze intact or cleared caatinga, where trees and shrubs are the dominant life form. Perennial grasses and forbs are rare, though a thick growth of annuals appears with sufficient rain. When the dry season begins, forage supplies decline drastically in both quantity and quality. Most woody species shed their leaves, which like herbs, soon dry and disintegrate, leaving little dry season forage. This annual period of nutritional stress is reflected in poor animal performance. Reproductive rates are low and substantial weight losses occur annually (Huss 1976, Ogden 1980).

Trials have shown that herbage production can be increased substantially by clearing the caatinga and planting introduced species such as bufflegrass (Cenchrus ciliaris)(Malechek 1980). This is an expensive alternative beyond the means of most small scale farmers. Traditionally, the caatinga is hand-cleared and burned to prepare cropland or herbaceous pasture. These clearings are short-lived and require maintenance to hold back reinvading brush. After a few years, production declines and the plot is abandoned. A fallow period follows in which the caatinga regrows and productivity is restored before the area is again cleared. The duration of the fallow period varies but is becoming shorter as uncleared land becomes scarce. Undesirable changes in the vegetation, increased soil erosion, and diminished productivity are the result.

A diet selection study in uncleared caatinga emphasized the importance of dried leaves of three tree species: catingueira

(Caesalpinia pyramidalis), sabià (Mimosa caesalpinifolia), and mororo' (Bauhinia forficata), in the dry season nutrition of sheep and goats (Pfister and Malechek 1986). A comparison of available forage and diet selection by sheep and goats on recently cleared and uncleared caatinga (Kirmse 1984) reinforced Pfister's findings and demonstrated that much of the purported gain in herbaceous production following clearing consists of coarse stem material which is not consumed. Reducing the cover of woody plants resulted in a threefold reduction in production of leaf litter. Sprouting (coppicing) stumps provided some green forage during the dry season, however, partially offsetting the impact of clearing on forage supply.

These studies recommend selective clearing (Pfister 1983) and sequential strip clearing (Kirmse 1984) as means of maintaining the dry season forage supply while realizing the benefits of clearing the caatinga, such as wood harvest and increased herbaceous production. This suggests that the traditional management scheme is sound but could be improved to meet changing conditions.

Brush Management

When brush eradication is not recommended, the alternative is brush management: "Management and manipulation of brush to achieve specific management objectives" (Kothmann 1974, p. 4). Brush management differs from brush control, defined as "reduction of brush to reduce its competition with more desirable species for space, light, moisture, and nutrients" (Kothmann 1974, p. 4). One objective of this project is to improve dry season forage production using methods that are economical and acceptable to the farmer. It is fortunate that all of the most promising and economical brush management techniques--

manual control, controlled burning, and grazing--are already in use in the caatinga, though their effectiveness is not fully documented.

The brush management literature of the semi-arid and arid tropics provides numerous examples of adapting varied techniques to particular objectives (Howell 1981). Matching management goals with techniques to accomplish them requires an understanding of the environmental requirements, economic and biological value, and probable response of the species involved. Ongoing studies at the CNPC will help formulate specific recommendations for improving animal production. This study provides information about the response of woody caatinga species to manipulations which may improve animal production.

Management of Coppicing Stumps

A review of brush management techniques used in the world's arid and semi-arid tropical shrublands and woodlands reveals many common problems. Among these is the incredible persistence of woody vegetation in spite of centuries of effort to remove it. Many woody species sprout from the stump or roots if damaged.

Most woody caatinga species coppice when injured. The only non-chemical techniques effective against this regrowth are laborious hand grubbing of stumps, repeated removal of regrowth, or intense burning. These methods are impractical over large areas or in dense stands. Traditional management dictates that the least desirable stumps are grubbed out or piled with slash and burned. Coppice growth on the remaining stumps must be slashed periodically. When a crop site is abandoned, coppicing stumps contribute to its rapid reforestation. Woodcutters rely on the stumps of sabiá (Mimosa caesalpinifolia) to produce a crop of salable posts within five years after cutting.

Foresters have long taken advantage of coppicing to improve forest production. Coppice methods insure fast, economical return to full stocking after harvest, maintain desirable species and genetic composition, shorten rotation times, and even convert cull trees to acceptable form (Hardesty et al. 1986). The woody plant's ability to coppice presents both a problem and an opportunity. This point of view is consistent with the philosophy of brush management: optimizing the desirable features while minimizing the undesirable features of a particular vegetation.

Objectives of This Study

This is a preliminary study designed to explore the possibility of manipulating coppicing stumps to improve caatinga management, particularly dry season forage production for small ruminants. Specific questions include:

1. Do different species respond differently to manipulation of coppice growth?
2. Does the season in which the tree is cut affect subsequent coppice production?
3. Does defoliation of the coppicing stump affect future coppice production by the stump?
4. Is abscission phenology of coppice growth affected by manipulation of coppicing?

This is a study of the responses of individual trees to manipulation, not an attempt to describe the response of entire stands. Nor are the physiological mechanisms involved in the tree's responses determined. Research on these questions logically follows preliminary work such as that reported here. However, results of this study are

interpreted in terms of both management implications and physiology in order to suggest profitable areas for future research.

CHAPTER II

LITERATURE REVIEW

Many woody species sprout following any type of decapitating injury, such as cutting, burning, browsing, or frost. This response occurs in all plant groups and has obvious survival value, allowing the plant to regenerate using the root system and reserves developed earlier (Keeley and Zedler 1978).

Most woody forage species in the caatinga sprout abundantly and coppice growth of many of the normally unpalatable species is palatable to sheep and goats. In addition, coppice growth remains green for several months after intact trees have shed their leaves. Coppice shoots grow faster and for longer periods than do seedling shoots (Wilson 1968, Walters 1972). All of these observations suggest that coppice growth is a valuable forage resource. Understanding the factors that control coppicing would allow land managers to manipulate it, regardless of whether the objective is to eliminate it or to change the species composition or structure of the vegetation.

Given that coppicing has caused the failure of many brush control programs, but that it is also a useful forest management tool, surprisingly little information is available about the factors influencing coppicing and the physiological mechanisms involved. Perhaps as Blake (1983) suggests, this lack of information is limiting our ability to manage coppicing stands to achieve their full productive potential.

Factors That Affect Coppicing

Numerous factors have been found to correlate with coppicing, including plant species, ecotype, site, age, diameter and vigor of the parent tree, height of the stump, origin and placement of the sprouts, interactions with neighboring plants, stem and root carbohydrate levels, growth regulators, season of cutting, and defoliation of regrowth.

Most studies have concentrated on temperate tree species, with the addition of a few humid tropical species. Yet the range of known coppicing behaviors within this group is so broad that assumptions concerning the importance of a particular factor to an unstudied species are risky, especially in a little known but unusual environment such as the caatinga.

As with extrapolations from one species to another, assumptions about the behavior of a single species from one site to another are also unreliable because sub-specific genotypic differences may exist. Comparing the coppicing ability of swamp tupelo and water tupelo, Hook and DeBell (1970) found distinct differences not only between the two species, but between ecotypes of the same species. Nor do associated species necessarily have similar response patterns. Walters (1972) observed striking differences in the sprouting ability of five different commercial timber species growing together in Hawaii. In some cases, one species may sprout vigorously while a congener on the same site lacks this capacity (Keeley and Zedler 1978).

The age and size of the parent plant are also important. Coppicing ability generally decreases with age (Smith 1962, Daniel et al. 1979), although the age at which sprouting capacity begins to decline

varies with the species and circumstances. Coppice production is generally thought to increase with stem diameter to a certain optimal point beyond which it declines. In many cases, however, it is not clear whether diameter is a controlling factor or only correlates with age. Age and diameter are related, and the age at which a species achieves a given diameter is very site specific, making estimations of age based on diameter difficult. Among an even-aged group of trees, Belanger (1979) detected a linear relationship between stump diameter and coppice yield of sycamore, which he attributed to the greater reserves available to larger trees. On this basis, he predicted greater longevity and productivity from larger stumps. Hillis and Brown (1978) found that the larger stumps among stumps of similar age produced more vigorous coppice. Within a given age group, diameter and vigor are also related. Trees with a superior genotype or more favorable microsite would be expected to be more vigorous, achieve greater diameter growth, and produce more vigorous coppice. Again, the causal relationship is uncertain, but it is clear that age, diameter, and vigor all correlate with coppice production. A better understanding of the actual mechanisms involved is needed before predictions can be made based on these factors.

The height of the stump affects coppice production. Belanger (1979) reported that the number of sprouts increased as stump height increased, but that growth and yield were not affected. He interpreted this to mean that lower stumps will produce fewer, more productive sprouts, causing stump diameter and root production to increase. A silviculture text (Smith 1962) advises cutting low stumps, explaining that the most vigorous sprouts come from the root collar or below.

Blake (1983), however, cites several cases where stump height did not affect production or where low stumps were ultimately less productive than higher stumps. He found that low stumps can be associated with either unusually high or low mortality, but suggests that low stumps reduce the incidence of butt rot in areas where this is a problem.

Confusion over the effect of stump height on coppice production may be due at least partially to the fact that coppice shoots vary in origin and growth potential. Coppice shoots arise from several sources, with the origin of the bud determining much about the shoot it produces. Woody plants have numerous dormant buds, which develop in the leaf axils and maintain a connection with the pith through the bud trace. Adventitious buds form later, often in the callus of a wound or on the roots, and have no bud trace connection with the apical meristem (Kramer and Kozlowski 1960). Water tupelo sprouts from both dormant and adventitious buds; the dormant bud shoots emerging within six weeks of cutting, while the adventitious shoots appear later, after the callus ring forms. Adventitious shoots were shorter and less vigorous. In contrast, swamp tupelo sprouted only from dormant buds (Hook and DeBell 1970). The number of dormant buds is limited by the age and surface area of the stump and, presumably, could be exhausted. Production of adventitious buds is thought to continue indefinitely (Smith 1962). For species producing both bud types, it is possible that treatments could determine the type of buds producing regrowth. Nothing has been written about the origin of coppice shoots in species typical of the caatinga.

Although much has been written about the effects of competition on plant growth, the importance of competition as a factor influencing

coppice regeneration has been largely ignored. Blake (1983) discussed density as a factor in managing short rotation biomass plantations, but the influence of plant competition is largely implied. No reference was found regarding the effect of competition on coppice regeneration in naturally occurring stands. The condition of neighboring plants must also be considered in managing coppice growth. Root grafting enables uninjured plants to capture the root reserves of injured plants and reduce their ability to sprout (Smith 1962). Wold and Lanner (1965) describe a case in which a 20-year-old "dead" stump began coppicing when a neighboring tree fell in a storm. Apparently growth-inhibiting auxin from the intact tree has been translocated via root grafts to the living stump, preventing coppicing. When this tree fell and the auxin supply was cut off, the stump sprouted. In this manner, the intensity with which the entire stand is treated may affect the response of individual trees.

The importance of carbohydrate reserves as a factor controlling coppice production has been debated for some time. In 1929, Aldous reported that seasonal fluctuations in sprouting correlated with changes in carbohydrate stores. Kramer and Kozlowski (1960) interpreted results of a study by Clark and Liming (1972) to mean that coppice vigor of oak declined as carbohydrate levels were depleted. After a detailed study of carbohydrate levels and coppicing in sweetgum, however, Wenger (1953) concluded not only that coppicing is not dependent on carbohydrates, but that carbohydrate accumulation is dependent on the amount of coppicing that has occurred. Factors such as day length and growth regulators, which complicate patterns of carbohydrate production, accumulation, and use, are discussed relative

to coppice production. While this study is frequently cited, implying that it is still considered the definitive work on the subject, carbohydrate level is frequently mentioned as a factor affecting coppice production. It is interesting that the subject has not been explored further using radioisotopes and other tools that have become available since Wenger's research was published.

Most of what we know about the normal functioning of an undisturbed tree may become irrelevant when decapitation brings about a drastic and instantaneous rearrangement of relationships between different plant parts. Growth regulators help reestablish homeostasis. Apical dominance is maintained by auxin translocated downward from the crown; its loss is thought to be the proximate stimulus for coppicing. Auxin is translocated with carbohydrates and thus acts only during periods of active photosynthesis. Auxin levels also decline with increasing moisture stress (Larson 1956). The fact that coppicing does not occur spontaneously during periods of moisture stress or photosynthetic inactivity suggests that reduced auxin level alone is not sufficient stimulus for coppicing. Complex interactions between the various growth regulators are more likely responsible. Blake (1983) reviews recent evidence that proximity to the root system, a source of water and growth-stimulating cytokinins and giberellins, may be a factor in coppice vigor.

Not all of the factors influencing coppice growth are subject to manipulation, but the number of factors involved requires that as many as possible be controlled during field experiments. In this study, the size of the tree's cut, the height of the stump, and the condition

of neighboring trees are controlled. Variables include season of cutting and defoliation of coppice growth.

The Effect of Season of Cutting on Coppicing

The season of cutting is one of the factors influencing coppicing that is easily manipulated. Clark and Liming (1972) found that unwanted blackjack oak could be controlled most effectively by identifying the season in which sprouting after cutting was least likely to occur. Cutting during the dormant period is generally thought to maximize coppice production (Smith 1962). Belanger (1979) was able to increase sycamore coppice growth sixfold by cutting during the dormant season rather than the period of most active growth. This pattern is confirmed in the work of Buell (1940), Blake (1972), DeBell and Alford (1972), Steinbeck et al. (1972), Cremer (1973), Pringle et al. (1973), and Zohar et al. (1975). However, there is evidence that this is not the only pattern of response to season of cutting (Hillis and Brown 1978, Hook and DeBell 1970, Odegbaro 1973, Roth and Hepting 1943). Because the physiological factors controlling sprouting are not completely clear, there is no satisfactory explanation for the various response patterns that have been observed to cutting in different seasons. One problem may be methodological, since the number of shoots produced, or height achieved by the dominant shoot, are often studied to the exclusion of biomass production. Differing growth patterns in different species further complicate comparisons.

Seasonal variation in carbohydrate levels, growth regulator activity, and available water may account for observed correlations between the season of injury and the magnitude of the coppicing

response. In 1953, Wenger observed that seasonal variations in sweetgum sprouting correlated with seasonal variations in auxin levels and that coppicing was least vigorous when auxin levels peaked. Because water is scarce much of the year in the caatinga, soil moisture may limit plant growth; thus coppicing capability may vary seasonally with soil moisture. Studies of the effect of soil moisture on coppice production by trees cut in different seasons have not been reported in the literature.

The Effect of Defoliation on Coppice Production

Herbivory is a natural form of defoliation to which many woody species have adapted, be it insect grazing in the canopy or browsing by ground dwellers. The manner of defoliation and the degree the plant can tolerate are partially determined by the type of defoliation most commonly experienced. There is evidence that young trees and shrubs may have mechanisms for avoiding herbivory that are not found in mature plants, which rarely experience drastic defoliation (Bryant et al. 1985). A problem arises when coppice growth is subjected to herbivory. Coppicing invokes juvenile growth characteristics that are different from those of either the seedling or the intact, mature tree (Schaffalitzky de Muckadell 1962, Zimmermann and Brown 1971). Coppice is browsed by ground-dwelling herbivores as if it were a shrub or young tree, but it is neither, and models of how seedlings and shrubs deal with herbivory may not be satisfactory for the coppicing stump. For example, though the coppicing stump has a fully developed root system, it lacks the root reserves typical of shrubs (Garrison 1972). As a tree it stored carbohydrates in its twigs and branches, and when

cut it lost not only its photosynthetic capacity but also its reserves. In some cases coppice growth has been observed to be more palatable than the foliage of mature trees (Hallisey and Wood 1976, Leege and Hickey 1971, Lieberman and Lieberman 1984, Reynolds and Sampson 1943), suggesting chemical differences in the foliage. However, there is still no satisfactory paradigm explaining how the coppicing stump deals with herbivory.

Manually removing all or part of the canopy of intact or coppicing trees is sometimes practiced as a means of coppice management. Davidson (1983) tested the idea that thinning coppice clumps could improve development of coppice shoots by hybrid poplars. He concluded that the practice did not affect the number of sprouts produced or the diameter of the dominant shoot, although the height of the dominant shoot decreased. Unfortunately, biomass production was not addressed. In a study of the effect of frequency of cutting on the shrub Codariocalyx gyroides, Lazier (1981) found that stem biomass production declined with increasing frequency of cutting but that leaf biomass was not significantly affected. Lopping top growth of trees is a common way of harvesting browse. Lopping mature Diospyros melanoxylon was found to affect only leaf production (Kotwal 1981). Trees up to 32 cm diameter produced more leaf material than uncut trees, but trees larger than 32 cm produced less than uncut trees. Most studies have not considered the effect of defoliation on leaf production, and much useful information has been lost due to the exclusive focus on wood production.

More attention has been given to the effect of frequent harvesting of coppice growth on stump survival. Short-rotation coppice

forestry is being used increasingly for energy production, but its success depends on the stump's ability to produce successive generations of coppice. Heavy stump mortality following coppicing is not unusual (Jacobs 1955, DeRezende et al. 1980), and it tends to increase with each successive harvest even in the apparent abscence of disease. Blake (1983) notes that adequate spacing is an important factor in stump survival. Increasing size and age and changes in carbohydrate levels which are thought to affect coppice production, may similarly affect repeat coppicing performance.

Abscission and Leaf Flushing Phenology

Phenology was not a variable in these studies, but is a critical plant activity that is affected by the treatments being applied in this study. Phenology is controlled by several of the same factors thought to be responsible for the tree's response to season of cutting and defoliation of coppice growth. The phenological event most influenced by these treatments is abscission phenology.

Abscission is a physiological process controlled by several internal factors: water status, carbohydrate and nitrogen levels, and growth regulators. Environmental factors, including day length, temperature, water status, wind, soil factors, diseases, and herbivores, all affect abscission indirectly through their effect on plant physiology. Abscission is almost always advantageous to the plant (Addicott 1978). Healthy leaves are not normally abscised. When resources become limiting, plant organs come into competition and the weaker sinks are abscised to maintain homeostasis within the remaining plant parts. Thus abscission can be considered an indicator of change within the plant.

Species growing in regions with regular climatic fluctuations develop deciduous leaf abscission patterns as a beneficial adaptation. Trees of tropical regions with distinct wet and dry seasons, such as northeast Brazil, are characterized by leaf fall early in the dry season and new foliate production shortly after rains commence (Alvim 1964, Kozlowski 1973). In this situation, moisture stress mediated by increased abscisic acid production is thought to trigger abscission (Addicott 1978).

Water status may not always be the critical factor. A study of the flowering phenology of 30 associated tropical species demonstrated at least three patterns of response to seasonal environmental changes: response to moisture status (hydroperiodic); constant phenology year to year, apparently keyed to photoperiod or temperature; and no clear correlation with external factors. While other phenological events such as abscission may show these same patterns of response, each phenological event may instead be triggered by a different environmental stimulus. This question has not been addressed in the literature.

Phenological patterns do not remain constant throughout the life of a plant. Juvenile plants of some species retain leaves longer than do mature plants of the same species (Schaffalitzky de Muckadell 1962). As a tree matures, leaves are retained for shorter periods due to limited light and mineral resources (Addicott 1978). Increased abscisic acid is thought to trigger abscission, and abscisic acid production increases with leaf age and moisture stress. Mechanical factors may also be involved. As a plant increases in size, internal resistance to water movement reduces its capacity to maintain a favorable water balance (Borchert 1975).

Several physiological conditions connected with coppicing are known to delay abscission, including high carbohydrate, auxin, and nitrogen levels (Addicott 1978). High nitrogen levels are usually associated with high-auxin plants, such as young trees and leaves, which tend to abscise later than older trees and plant parts. While it is unlikely that the coppicing tree has access to more soil nitrogen than uncut trees, available storage in new branches and twigs is reduced because of limited biomass, which perhaps results in higher concentrations of carbohydrates and nitrogen in the stems. Although a reduction in translocated auxins is thought to induce coppicing, the new shoots quickly begin to produce auxin themselves, perhaps accumulating high levels in the coppicing stump in order to reduce competition among new shoots, which indirectly affects leaf-fall.

Although the time of new leaf production (flushing) was affected by browsing treatments in this study, no comparable instance was found in the literature. Many of the physiological processes which affect plant growth are altered by browsing, thus it is conceivable that browsing could affect flushing.

Flushing is assumed to be tied to the return of the annual rains, but the situation may be more complex. Alvim (1960) and Magalhaes and Angelocci (1976) have shown that a critical degree of moisture stress (-12 bars) is needed to break bud dormancy in at least one tropical species, Theobroma cacao. Observations of flushing following atypical mid-dry season rains (Pfister 1983) suggest that such a requirement does not affect caatinga tree species, but there is insufficient information available to state with certainty that flushing is triggered by rainfall alone.

Conclusions

Although numerous studies demonstrate correlations between coppicing behaviors and various environmental, physiological, and cultural factors, the basis for these correlations remains obscure. Undoubtedly this is due to the complexity of the interactions between the numerous physiological processes in the plant and its environment. Until recently, our lack of knowledge may have been understandable: we lacked many of the investigative tools currently available, coppice forestry was not widely practiced, and undesirable coppicing could often be controlled with herbicides. This situation is changing, however. Coppice forestry is attracting increasing attention as a means of alleviating worldwide fuelwood shortages. Herbicides are being used with increasing caution as their environmental effects and cost effectiveness are questioned. These trends suggest a growing need for a clearer understanding of the coppice phenomenon. Given the tools presently available, plant physiologists should be able to resolve many of the questions raised in this review. In the meantime, however, we must continue to rely upon correlations and extrapolation from the few existing studies for explanations of, or predictions about, coppicing in the caatinga.

CHAPTER III

STUDY SITES

An Ecological Description of the Caatinga

Caatinga is the unique vegetation of the arid inland areas of northeast Brazil. The nine states of the northeast (Alagoas, Bahia, Ceará, Minas Gerais, Paraiba, Pernambuco, Piaui, Rio Grande do Norte, and Sergipe) constitute 18 percent of Brazil's land area (Campos 1941). Caatinga covers roughly half of this, about 830,000 km^2 (Valverde 1969). Certain unusual climatic and edaphic conditions characterize the caatinga, and land use also influences its distribution. Before describing the caatinga vegetation, the climate, geomorphology, soils, and history of the region will be described as they relate to the vegetation.

Climatic Influences. Northeast Brazil is the farthest east extension of the South American continent, lying between 3° and 18° S latitude and 35° to 46° W longitude (Freise 1938). The climate of this area is not typical of either the equatorial or subtropical region. There is a distinct dry season 6 to 11 months long, rain falls in summer rather than winter, and severe droughts and disastrous floods are common (Eiten and Goodland 1979). These anomalies are the result of latitudinal position and proximity to a cold ocean current (Axelrod 1979).

The caatinga occurs in a transition zone where both northern and southern hemispheric circulation patterns are influential, though neither dominates. Where the cold Benguela current rises off the coast of northeast Brazil, a layer of cool air forms, displacing warm, moist air masses and preventing rain. Cool air also stabilizes anticyclonic circulation

patterns and weakens storm fronts, further reducing precipitation (Axelrod 1979).

Precipitation. For rain to occur, it is essential that warm maritime air masses reach the inland regions (Valverde 1969). Tropical continental air masses usually block this but when warm dry anticyclones mix with the trade winds or when warm air masses from lower Amazonia condense over the caatinga, it rains (Axelrod 1979, Shanahan 1953). So precarious is the combination of circumstances that causes rain, that it is not unusual for it to fail altogether for several consecutive years (Eidt 1968, Shanahan 1953, Valverde 1969). Freise (1938) analyzed rainfall data from northeast Brazil and found the predictability of rainfall declined with declining average annual rainfall. This is consistent with observations from other arid areas (Thornwaite 1956).

Average annual rainfall figures are misleading, however. Annual rainfall in the caatinga varies from 300 to 1000 mm/yr, generally decreasing in the interior, but few areas receive less than 500 mm/yr (Christiansen-Weniger 1977). This is not particularly low; the problem is the timing and distribution of precipitation. The rainy season varies within the region, usually beginning between October and December, and continuing until April or May. In a "normal" year, 90 percent of the annual precipitation falls during this period.

Storms are intense. All of the rain in a given month may come within a few days. Individual storms rarely last more than 45 minutes, and are concentrated over areas less than 2 km^2 (Freise 1938). Often, more rain falls than the soil can absorb, causing floods and soil erosion. High potential evaporation also decreases the effectiveness of precipitation.

Temperature. Unlike precipitation, temperatures are relatively uniform in the northeast. The average annual temperature range is 22-26°C (Camargo 1965). Christiansen-Weniger (1977) points out that while this is near optimum for plant growth, leaf temperatures may be higher due to the intensity of radiation near the equator and that for plant growth, temperature extremes are more critical than averages. Over a 40 year period, the average annual maximum was 36°C, the average annual minimum was 18.6°C, and the absolute maxima and minima were 41.5° and 11.6°C, respectively (Christiansen-Weniger 1977, Freise 1938).

Wind. There is little information available about the influence of wind in the northeast. Freise (1938) summarizes the direction of prevailing winds and the percent of the time they occur: southeast 35 percent, east 22 percent, northeast 14 percent. Air speed rarely exceeds 10 m/sec, the median being less than 2.5 m/sec (Freise 1938). Dry winds from high pressure zones in the east aggravate existing moisture deficiencies and wind erosion is a problem during the dry season (Christiansen-Weniger 1977, Shanahan 1953).

Evaporation. Potential evaporation in the caatinga ranges from 1000-1500 mm/yr (Camargo 1965, Eiten and Goodland 1979). Potential evaporation is a function of temperature, windspeed, and relative humidity, and together with precipitation, determines the water balance of the plant and has a major influence on regional vegetation. The relationship between precipitation, temperature, and evaporation is the basis of Walter and Leith's (1967) climate diagrams. The diagrams plot monthly average temperature and precipitation on axes where 10°C are equivalent to 20 cm of rain, and the

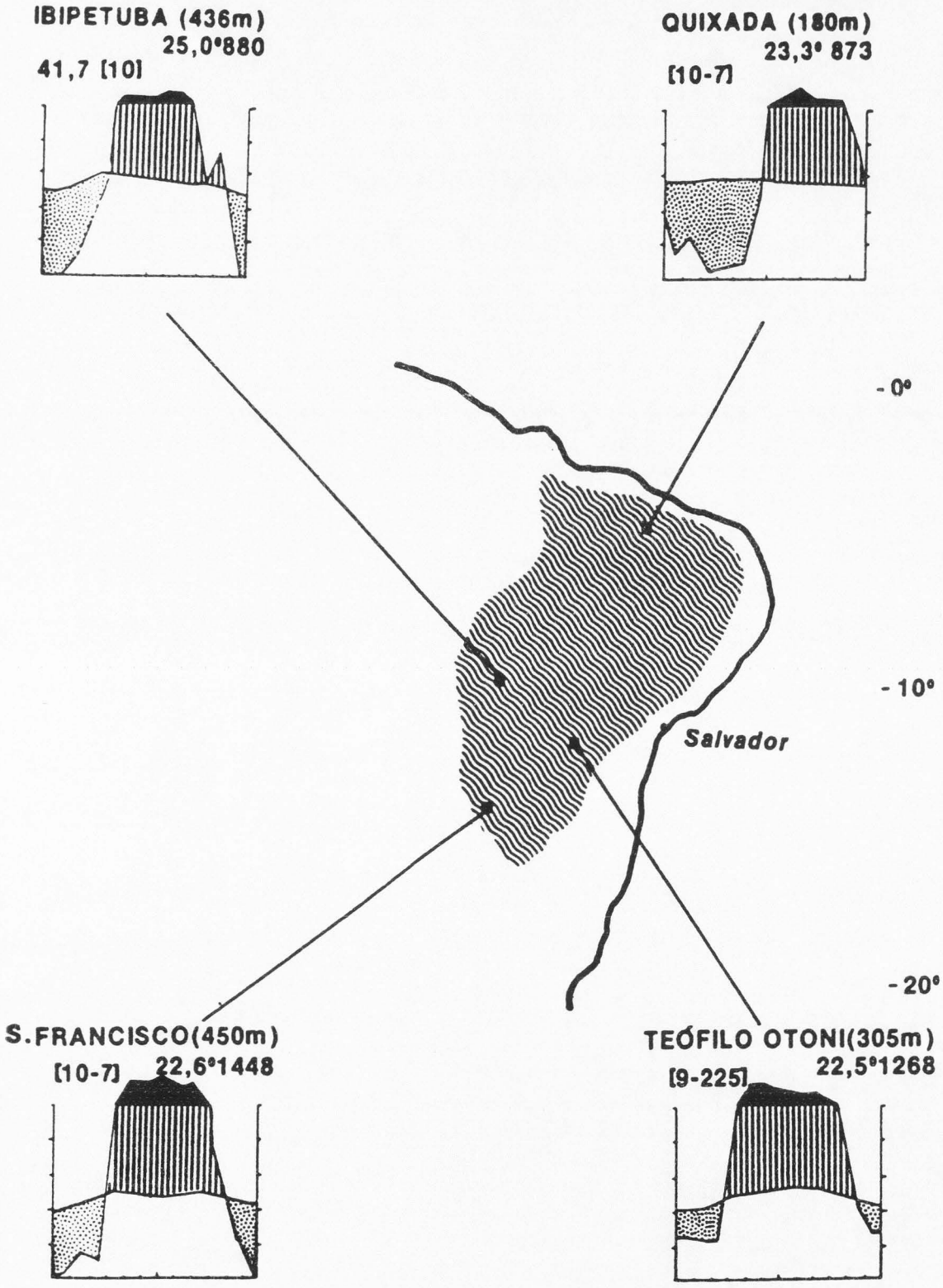

Figure 2. Climate diagrams for the caatinga of northeast Brazil (climate diagrams from Walter and Leith 1967).

duration and intensity of humid and arid periods are apparent. Climate diagrams for locations in northeast Brazil are presented in figure 2.

Geologic History. Understanding the geologic history of the northeast helps explain its aridity and the occurrence of the vegetation that makes the area unique. The dominant feature of the region is the extensive peneplain known as the Borborema plateau. This consists of Precambrian granite, schist, gneiss, quartzite, and other crystalline rock (Shanahan 1953). Limestone and sandstone were deposited over this base when it was submerged during the Cretaceous period. These formations were uplifted in the early Tertiary and have been dry for the past 50-65 million years. The erosive force of rivers, torrential rains, and intense heat have carved the current landscape from this ancient foundation.

Northeast Brazil is relatively level. The eastern edge of the plateau is slightly higher and its broken edges form scarps overlooking the coastal lowlands. Along its western side, the plateau dips under more recent strata, the edges of which form a second abrupt escarpment.

The average elevation is between 200-300 m, but there are numerous uplands which, like the escarpments, may rise 1000 m above the plain (Mason 1930). The origin of these uplands varies. Remaining sedimentary deposits form broad, flat-topped "taboleiros" with steep sides (Freise 1938). "Serras" are inselbergs, remnants of older crystalline formations (Valverde 1969). These have a rounded appearance and different soils and vegetation than the taboleiros.

The difference in the origin of the different land forms is expressed by the vegetation. Cole (1960) suggests that the various types of vegetation (mata, cerrado, and caatinga) characterize different phases of the erosion cycle. He predicts that as the plateau is continually broken down,

the caatinga will advance because of its adaptation to the crystalline substrate exposed.

This history and the landscape it has produced also affects water distribution. The uplands have an orographic effect and capture more precipitation than the surrounding plains. Where sedimentary rock remains, its porosity compounds climatic aridity because water is not retained. There is no permanent water table in the uplands of the caatinga, with the possible exception of the sandstone plateaus of Piaui (Eiten and Goodland 1979). Sternberg (1956) has emphasized the importance of the serras as a water source and suspects that agricultural activity here has caused many springs to fail and intensified the scarcity of surface water. Perennial streams are scarce and most surface water is found in acudes, the man-made reservoirs found throughout the region.

Soils. The occurrence of erosion surfaces of varying age and origin helps explain the diversity of the soils in the northeast. Weathering crystalline and sedimentary parent materials produce distinctly different soils. The prevalent soil orders in the region are alfisols, aridisols, and entisols.

Alfisols develop from crystalline rock and are the predominant soils of the region (Beek and Bramao 1968, Camargo 1965, Donahue et al. 1977). They are moderately shallow, neutral to weakly acid, have medium to high base saturation, and are characterized by clay accumulation in the B horizon (Donahue et al. 1977).

Aridisols are well developed soils originating in arid areas where little water leaches through the horizons. The aridisols of the northeast are characterized by low organic matter and an argillic horizon. With sufficient water, these soils are very productive.

Entisols are soils without horizon development. These soils occur on recently deposited material or under conditions in which soil development is very slow. In the northeast, these soils have a loamy or clayey texture and are well drained.

In general, the soils of the caatinga are shallow, well drained, low in organic matter, and relatively high in soluble bases (Eiten and Goodland 1979, Ramos 1981, Valverde 1969). These soils are naturally fertile, but their water storage capacity is limited. In the dry season, precipitation limits soils moisture, but in the rainy season, rainfall frequently exceeds storage capacity and accelerated erosion and flooding occur. Soil losses also occur during the dry season due to wind erosion. Wind is particularly destructive during drought or when ground cover is sparse. Cole (1960) points out that a balance is needed between soil removal and soil renewal if fertility is to be maintained. Thus, excessive erosion can reduce water storage capacity and fertility.

Vegetation. Literally, "caatinga" means light forest (Eyre 1963). A more precise definition is: the vegetation formation of the semi-arid (less than 1000 mm/yr) interior of northeast Brazil, dominated by deciduous or succulent woody species (Lima 1965, Smith 1945, Veloso and Strang 1970). Subtypes occur within the caatinga, but it is distinct physiognomically and taxonomically from the forests and grasslands surrounding it.

After four centuries of disturbance, it is difficult to visualize the original condition and extent of the caatinga. It is of recent (Tertiary) origin, having evolved from dry forest in response to increasing aridity in the northeast (Axelrod 1979, Sarmiento 1975). Sarmiento (1975), Smith (1945), and Mason (1980) concur that abuse of the surrounding forest has allowed the caatinga to expand beyond its original borders. Lima (1965)

states that caatinga may be a disclimax on degraded forest land, a seral stage in the regeneration of disturbed forest, or the climax vegetation for a site, depending on environmental factors and the history of the site.

The diversity of the caatinga vegetation is apparent when examining the different systems that have been used to identify subtypes within it. Various authors have recognized anywhere from two to twelve different types of caatinga since Martius first described it in 1869 (cited in Lima 1965). Approaches to classifying the caatinga vegetation are described in detail by Quieroz (1985).

Study Sites

Studies were conducted at two sites within the state of Cearà. The Sobral site was located at the National Sheep and Goat Research Center, near the town of Sobral.

The Quixadà site was located at Fazenda Iracema, an experimental farm operated by the state agricultural research organization, EPACE. The fazenda is located near the town of Juatama, in the municipio of Quixadà.

In the interior of Cearà, rainfall is normally concentrated between January and April. This is variable, however, and extended droughts, such as that of 1981-1983 are common. Average annual rainfall for Sobral is 759 mm. During the studies (1982-1984), annual rainfall was 650, 447, and 986 mm, respectively. Average annual rainfall for Quixadà is 873 mm and was 710, 275, and 769 mm during the study. Other climatic features are typical of the region as described earlier.

Both sites have shallow (<.5 m), well drained soils underlaid by crystalline rock. The dominant soils at the Sobral site are sandy-gravelly litosols (orthents), non-calcic brown soils (paleargid, haplargid), and an

eutrophic red-yellow podzol (ustalf)[1]. The Quixadà site has mostly litosol and non-calcic brown soils. Both sites have a gently rolling topography.

Both sites were located in mature caatinga stands, but the vegetation at the two sites varied. The Sobral stand was dominated by pau branco (Auxemma oncocalyx), a species which is rare in Quixadà. Woody species which dominate the Quixadà site include jurema preta (Mimosa acutistipula), catingueira (Caesalpinia pyramidalis), and sabià (Mimosa caesalpinifolia). All of these species are common in Sobral. Marmeliero (Croton hemiargyreus) and mufumbo (Combretum leprosum) are frequent at both sites, but not dominant species. Mororo' (Bauhinia forficata) is much more frequent in Sobral, and a variety of species which together compose a small portion of the vegetation in Quixadà do not occur at all in Sobral. Live jurema preta occurred more frequently in Quixadà. This is significant because this is an early seral species which does not persist in a maturing stand (Queiroz 1985), suggesting that the Quixadà stand may be somewhat younger than the Sobral stand. However, both stands are considered "old" (40-60 years) by local residents. These were dense (23,000 stems/ha in Quixadà), closed stands 6-10 m high.

Species Studied. The species selected for study are common throughout the region. In Sobral, these included pau branco, sabià, marmeliero, and catingueira. Sabià, catingueira, marmeliero, and jurema preta were studied in Quixadà.

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[1]Soils are described using Brazilian terminology, as they were mapped by Augmar Drumond Ramos. The suborders described in Soil Taxonomy are given in parenthesis as interpreted from Queiroz 1985.

Catingueira occurs in more different plant associations and habitats than any other species studied. It was a dominant species on both sites, both in terms of frequency and size. This tree tends to become hollow with age and burns rapidly, limiting its wood value. Catingueira is one of the first trees to leaf out when the rains begin and the foliage is eagerly sought by livestock. After a few days the foliage acquires a strong, pungent smell and is no longer browsed until the dry season when the leaves have dried and fallen. It is not clear if the smell itself is repellent or if it is incidental to a chemical change which reduces palatability. This characteristic ensures that catingueira foliage will be reserved for dry season forage.

Marmeliero is a small tree, rarely reaching 8 m in height or 10 cm in diameter. It has limited value for construction or firewood and is not normally browsed by livestock. Marmeliero leafs out if rains occur during the dry season, as happens occasionally, and is browsed at this time (Pfister 1983). This tree tends to form dense stands and is considered an invader, often taking over cleared pastures or disturbed areas.

Jurema preta is an evergreen tree which is avidly browsed year-round by all classes of livestock. The compound leaves are very small, making them difficult to locate when shed and branches are frequently out of reach of browsers. These two factors restrict forage value somewhat. Leaves are exchanged during the dry season when as much as 70 percent of the foliage may be shed. Jurema preta's dense wood is valuable for fenceposts, charcoal, and firewood.

Pau branco wood is used for construction, furniture making, and fuelwood. This is considered one of the more valuable timber species in the

caatinga. The foliage is not browsed by sheep and goats, although cattle find it palatable (Braga 1960).

Sabià is a small tree highly preferred for fenceposts, and as long, hot burning firewood suitable for industrial processes. Sabià's foliage is extremely palatable to sheep and goats throughout the year.

CHAPTER IV

THE EFFECT OF SEASON OF CUTTING ON COPPICE BIOMASS PRODUCTION

The season in which a tree is cut is an easily manipulated factor known to influence coppicing. Cutting during the dormant season generally maximizes subsequent coppice biomass production. In northeast Brazil, dry season land clearing is most common because crop production tasks are reduced and conditions for cutting and burning are favorable. Since some clearing goes on year-round, it is conceivable that more land clearing could be shifted to another season if significant advantage was expected.

This study seeks to determine if the usual pattern of coppice biomass production in response to season of treatment prevails in the caatinga. Specific questions include:

1. Does season of cutting affect subsequent biomass production by coppicing stumps of catingueira, sabià, pau branco, marmeleiro, and jurema preta?
2. Is stump mortality affected by the time at which the tree is cut?
3. Is the ratio of leaf biomass to stem biomass affected by the time the tree is cut?
4. Does seasonal variation in cutting provide better management options for the caatinga?

Methods

A randomized block design was used at both sites, blocking on topographic trend and minor changes in species composition. Four treatments were applied to plots in each of the three blocks. Six

trees of each species were selected per plot. These trees were within the modal diameter class for the species in that stand and showed no sign of injury or disease. The dates for the seasonal treatments were determined by the rainfall pattern. The early dry season plots were cut in July 1982, mid-dry season plots in November 1982, early rainy season plots in January 1983, and late wet season plots in May 1983. Because trees are normally cut in the mid-dry season, this was considered the check, or control treatment.

Treatment consisted of traditional land clearing by commercial woodcutters using hand tools. All woody plants were cut, the usable wood removed, and the slash piled away from the stumps being studied. Trees were cut at a standard 30 cm height. Plots were protected from grazing throughout the study.

At the end of the growing season (August 1983), two coppicing stumps of each species from each plot were randomly selected for harvest. The height and diameter of each coppice clump were measured; then all regrowth was cut from the stump. The harvested material was separated into leaf and stem fractions, oven dried at 65°C for 48 hours, and weighed. The heights and diameters of the unharvested coppice clumps were recorded. Regression equations were developed to relate leaf and stem biomass production to height and diameter for each species and treatment. This allowed prediction of biomass production by stumps that were not destructively sampled (Guy 1981, Ludwig et al. 1975, Uresk et al. 1977). At the end of the second growing season (August 1984), all previously unharvested stumps were harvested in a similar manner.

Variables analyzed include stem biomass, leaf biomass, total biomass, and ratio of stem biomass to leaf biomass. Homoscedasticity was verified using Cochran's test (Guenther 1964). Analysis of variance was performed using the SAS statistical package. Means were compared using Fisher's protected LSD test at alpha = .05.

Results

1983 Biomass Production. In 1983, leaf fall occurred simultaneously at both sites precluding collection of leaf production data for most species in Quixadà. When leaf and stem data were available, the changes in biomass production with season of cutting were consistent between stem and leaf fractions. Because much more stem material was produced, it tended to dominate the total production variable. Leaf material is more subject to loss or damage from storms or insects than stem material, leaving stem biomass the single most reliable variable examined.

Cutting late in the wet season did not allow enough time with conditions suitable for coppicing until rains began the following growing season. Omitting consideration of the late wet season treatment group, some trends became apparent in the first year.

Production of both leaf and stem biomass by trees cut early in the wet season was less than biomass production by trees cut at either time during the dry season. There was no clear distinction in production between trees cut early and trees cut later in the dry season (Tables 1-3).

Table 1. Mean coppice production (g dry wt) by individual trees cut in different seasons. Sobral, 1983.

Data Source and Treatment Species	Stem Wt (n)	Leaf Wt (n)	Total Wt (n)	Leaf/Stem Ratio (n)
		Catingueira		
early dry*	312 a (12)	286 a (12)	597 ab (12)	.8949 b (12)
mid-dry	391 a (30)	341 a (30)	731 a (30)	.9127 b (30)
early wet	139 b (17)	271 a (17)	410 b (17)	1.8828 a (17)
late wet	0 c (18)	0 b (18)	0 c (18)	-
		Marmeleiro		
early dry	215 a (8)	124 a (8)	339 a (8)	.5232 a (8)
mid-dry	166 a (11)	138 a (11)	304 a (11)	.8334 a (11)
early wet	104 a (12)	140 a (12)	245 a (12)	2.0245 a (12)
late wet	0 a (6)	0 a (6)	0 a (6)	-
		Pau Branco		
early dry	569 b (20)	321 b (20)	890 b (20)	.5867 b (20)
mid-dry	735 a (30)	442 a (30)	1176 a (30)	.6719 b (30)
early wet	349 c (18)	275 b (18)	624 c (18)	.8765 a (18)
late wet	0 d (17)	0 c (17)	0 d (17)	-
		Sabià		
early dry	399 a (19)	241 a (19)	639 a (19)	.6419 c (18)
mid-dry	297 ab (31)	212 a (31)	509 a (31)	.7419 b (31)
early wet	231 b (19)	198 a (19)	429 a (19)	.8886 a (18)
late wet	0 c (18)	0 b (18)	0 b (18)	-

For each species value within a column followed by the same letter are not significantly different ($P \leq .05$).

*Dates are July 1982, November 1982, January 1983, and May 1983 respectively.

Table 2. Mean stem production (g dry wt) by individual trees cut in different seasons. Quixadà, 1983.

Species and Treatment	Catingueira (n)	Marmeleiro (n)	Sabià (n)
early dry*	249 a (18)	137 a (19)	326 b (18)
mid-dry	204 a (28)	184 a (23)	591 a (25)
early wet	41 b (18)	214 a (19)	351 ab (19)
late wet	0 b (18)	0 b (17)	0 c (18)

Values within a column followed by the same letter are not significantly different ($P < .05$).

*Dates are July 1982, November 1982, January 1983, and May 1983 respectively.

Table 3. Mean coppice production (g dry wt) by individual jurema preta cut in different seasons. Quixadà, 1983.

Data Source and Treatment	Stem Wt (n)	Leaf Wt (n)	Total Wt (n)	Leaf/Stem Ratio (n)
early dry	3974 a (17)	261 b (18)	4012 a (16)	.0805 b (15)
mid-dry	1837 b (20)	392 ab (20)	2229 b (20)	.2159 b (20)
early wet	1421 b (22)	523 a (22)	1944 b (22)	.4039 b (20)
late wet	17 c (17)	18 c (17)	36 c (17)	2.0965 a (6)

Values within a column followed by the same letter are not significantly different ($P < .05$).

*Dates are July 1982, November 1982, January 1983, and May 1983 respectively.

Species occurring at both locations showed similar patterns in response to season of cutting and produced comparable amounts of biomass (Tables 1-3).

For all species except marmeleiro, the ratio of leaf biomass to stem biomass decreased with increasing time since treatment, consistent with the observation that leaf production dominated the early phase of coppice growth.

Some differences in biomass production between species were observed. Catingueira followed the general trend, producing more stems and leaves when cut in the early dry season (Tables 1 and 2). Jurema preta produced the most when cut in the early dry season. Production for the mid-dry and early wet season cuttings did not differ significantly from one another (Table 3). Dry season leaf production data are unreliable, however, because the tree is an evergreen, exchanging leaves at this time. Although marmeleiro followed the general trend, the season of cutting did not significantly affect production the first year. Marmeleiro cut in the early wet season produced more leaf than stem. Total weight and stem weight of pau branco were significantly different for each season of cutting (Table 1). Unlike most species, it produced most when cut in the mid-dry season. Leaf production by sabià did not vary significantly with treatment, but there were differences in stem production between the two sites (Tables 1 and 2). In Sobral, the maximum stem production occurred with early dry season cutting, while mid-dry season cutting was intermediate between early dry and early wet season cutting. In Quixadà, mid-dry season cutting maximized production and early wet season cutting was intermediate between the two dry season treatments.

1984 Biomass Production. Treatments were completed during the 1983 growing season, allowing all treated stumps an equal amount of time to grow during the 1984 season. Data are not available for the Sobral site in 1984 due to the unusually long rainy season, making further comparisons between the two sites impossible. In Quixadà, results from 1984 are consistent with those from 1983 (Tables 2, 3 and 4). Leaf and stem biomass production by trees of all species cut in the late wet season continued to lag behind production by trees cut in any other season (Table 4). For both marmeleiro and sabià, production was maximized by cutting in the middle of the dry season. Jurema preta and catingueira responded most to cutting early in the dry season. Production by trees of all species cut early in the wet season was intermediate between the late wet season low and at least one of the dry season treatments.

There were no significant differences in stem production or total weight produced by marmeleiro (Table 4), nor had there been any the first year.

A valid analysis of variance was not possible for catingueira because of large differences in the variance of the treatment groups. However, it appears from examination of the means (Table 4), that early dry season cutting results in greater production, followed by early wet season and mid-dry season treatments.

Jurema preta and sabià still retained the effect of cutting in different seasons (Tables 3 and 4). Production of jurema preta following early dry season cutting remained the highest, but results from the early wet season cutting surpassed those from the mid-dry season

Table 4. Mean coppice production (g dry wt) by individual trees cut in different seasons. Quixadà, 1984.

Data Source and Treatment Species	Stem Wt (n)	Leaf Wt (n)	Total Wt (n)	Leaf/Stem Ratio (n)
		Catingueira*		
early dry+	1604 (12)	620 (11)	2250 (11)	.5800 (11)
mid-dry	796 (18)	279 (18)	1075 (18)	.3335 (18)
early wet	898 (10)	466 (11)	1390 (10)	.6579 (10)
late wet	406 (12)	225 (12)	631 (12)	.6591 (12)
		Jurema preta		
early dry	5317 a (12)	524 a (12)	5841 a (12)	.0812 a (12)
mid-dry	2082 b (14)	192 a (14)	2273 c (14)	.0978 a (14)
early wet	3189 b (12)	506 a (12)	4004 b (11)	.1267 a (11)
late wet	767 c (11)	167 a (9)	1061 c (9)	.3921 a (9)
		Marmeleiro		
early dry	438 a (12)	181 bc (12)	619 a (12)	.5799 a (12)
mid-dry	613 a (16)	289 a (16)	902 a (16)	.5880 a (16)
early wet	581 a (15)	263 ab (15)	844 a (15)	.5169 a (15)
late wet	313 a (12)	151 c (12)	463 a (12)	.9281 a (12)
		Sabià		
early dry	1186 a (13)	591 a (13)	1777 a (13)	.5180 a (13)
mid-dry	1584 a (19)	754 a (19)	2338 a (19)	.4759 a (19)
early wet	1130 a (13)	540 a (13)	1871 a (13)	.4090 a (13)
late wet	457 b (13)	225 a (13)	681 b (13)	.5339 a (13)

For each species values within a column followed by the same letter are not significantly different ($P < .05$).

*This data not suitable for valid analysis of variance--see text.

+Dates are July 1982, November 1982, January 1983, and May 1983 respectively.

treatment. Only late wet season results were significantly different for sabià.

The leaf to stem biomass ratio was not significantly different between treatments for any species in 1984. However, the ratio tended to be slightly higher for the late wet season treatments.

At the end of the second growing season, no mortality had occurred among trees of any species in Quixadà.

It is important to note in interpreting these results that great variability existed between trees in the same treatment group, reflected in means that differ by several orders of magnitude but are not significantly different by the LSD procedure. Conclusions based only on statistical significance may be overly conservative in this case, and examination of trends among those means, regardless of statistical significance, may be useful.

Discussion

The season in which some of these species were cut did influence the amount of subsequent coppice growth. This has several management implications. The most desirable species should be cut during the dry season to maximize future production. Less desirable species should be cut late in the rainy season to reduce future coppicing. When browse production is the goal, this scheme would favor production of preferred species and give them a competitive advantage in the regenerating stand. Dry season cutting also reduces the impact of treatment on forage production in the year of treatment if fallen leaves are collected or browsed before land clearing begins. When the objective is to control plant density, seasonal cutting treatments alone

will not be sufficient to cause mortality. However, a reduced biomass response may indicate vulnerability to auxiliary treatments.

The fact that differences in the leaf to stem biomass ratios tended to decline and become constant between treatments suggests that manipulating the season of cutting cannot cause any long-term shift in leaf production relative to stem production. Observations of coppice growth in the third and subsequent years suggest that this ratio continues to decline for several years. This study demonstrates that leaf production can be maximized only by maximizing total growth. The exception is in the first months of coppicing, when the leaf to stem ratio is quite high. Total production at this time is low, however, and prospects for maintaining the stump in this condition are limited.

The one evergreen species among those studied, jurema preta, exhibited a response to the season of cutting that was similar to those of the deciduous species. Factors controlling the response to seasonal cutting in deciduous species apparently affect jurema preta similarly regardless of its evergreen habit.

This study was designed as a survey to determine if factors known to affect the coppicing of temperate trees also affect the coppicing of tropical species in the caatinga. Temperate trees tend to produce the greatest coppice growth when cut during the dormant season, which corresponds to the dry season in the semi-arid tropics. All of the species studied produced the greatest coppice growth when cut at some point during the dry season or early in the rainy season. Although this study was not designed to test hypotheses regarding the mechanisms involved, some cautious speculation may be useful in interpreting our results.

When a tree is leafless, it still has a continuing energy demand for respiration. This is true even if a major portion of its biomass is removed by cutting. Most nonstructural carbohydrates in trees are stored in the above-ground woody material (Kramer and Kozlowski 1960). When a tree is cut, the stump has only the reserves remaining in the stump and roots. How long the stump must depend on these limited resources before new leaves are produced becomes a critical factor.

In the caatinga, cutting trees in the dry season or early in the rainy season allows time for the tree to coppice and the new shoots to produce and store carbohydrates before the next dry season. Cutting late in the rainy season does not allow the stump time to replenish lost carbohydrates, forcing it to survive the entire dry season on limited resources. This results in minimal reserves available for early dry season growth, which may affect future production. Production in marmeleiro and sabiá (Table 5) supports this idea.

In the case of catingueira and jurema preta, the response pattern is not as easily explained by carbohydrate storage (Table 6). The existence of different patterns of response to season of cut is consistent with the variability reported in the literature, and confirms the inadequacy of the carbohydrate theory alone in explaining this response. The relationship between production and movement of growth regulators and moisture stress may have as much bearing on this response as do carbohydrate levels (Kozlowski 1962, Larson 1956, Wenger 1953). Physiological processes are difficult and time-consuming to isolate and clarify, and observed response patterns can only guide physiologists seeking to understand them. In the meantime, recognizing response patterns gives the land manager new options.

Table 5. Relationship between coppice biomass production and the time between cutting and resumption of growth for marmeleiro and sabià.

Response	Season of Cut	Months Until Rain
high	mid-dry	2
high	early wet	0
low	early dry	5
low	late wet	7

Table 6. Relationship between coppice biomass production and the time between cutting and resumption of growth for catingueira and jurema preta.

Response	Season of Cut	Months Until Rain
high	early dry	5
high	early wet	0
low	mid-dry	2
low	late wet	7

CHAPTER V

THE EFFECT OF REMOVING COPPICE GROWTH ON SUBSEQUENT BIOMASS PRODUCTION

The traditional land management scheme in northeast Brazil could be improved in terms of its forage production potential. What is needed is a modification that will:

1. Maintain or increase dry season forage production.
2. Maintain or increase production of herbaceous forages.
3. Maintain or increase production of wood products.
4. Control regrowth of undesirable woody species.

It is also assumed that any real improvement would be both acceptable and accessible to small farmers, would be sustainable, and would enhance overall environmental stability. Farmers have attempted to control undesirable woody regrowth by slashing it and by allowing browsing livestock access to the regrowth. This study quantifies the response of several caatinga species to severe defoliation of coppice growth by browsing goats and manual removal of regrowth. Specific questions addressed are:

1. Does removal of coppice growth cause stump mortality?
2. Does removal of coppice from stumps stimulate compensatory growth?
3. Does manual removal of coppice growth cause the same response as heavy browsing?
4. Do different, associated species respond differently to heavy defoliation of coppicing stumps?

Methods

Treatments consisted of no defoliation of coppice growth, one instance of manual removal of coppice, two instances of manual removal of coppice, and two periods of heavy browsing by goats. Each treatment was applied to one plot in each of three replications, in a randomized block design. Six trees of each of the species studied were included in each plot. These trees were within the modal diameter class for the stand and had no sign of injury or disease. Plots were clearcut in the middle of the dry season (November 1982) using hand tools in the traditional manner. Usable wood was removed and the slash piled away from the stumps to be studied. Stumps were cut at 30 cm above ground and protected from grazing. All stumps coppiced at the beginning of the 1983 rainy season. In March of 1983, the first treatments were applied.

Manual removal of coppice was accomplished by cutting all sprouts from the stump at the point of origin. The number of sprouts was recorded, the material removed sorted into leaf and stem fractions, oven dried at 65°C for 48 hr and weighed.

Plots to be browsed were fenced and supplied with water. The double sampling technique using dimensional analysis described earlier was used to estimate coppice biomass. Two randomly selected trees of each species in each replication were harvested. The height, longest diameter and a perpendicular diameter of each coppice clump was measured. Coppice material was then cut from the stump, separated into leaves and stem, oven dried and weighed. The dimensions of the remaining coppice clumps were recorded and used to estimate production with regressions developed from the harvested clumps.

Ten young castrated male goats averaging 25 kg were allowed to browse freely on the plots for 21 days until most forage was consumed and body weight loss occurred. The plots averaged .18 ha, resulting in an effective stocking density of 55.6 goats/ha. Stumps were examined after browsing, noting any remaining sprouts and the degree of bark removal.

The stumps produced new coppice within days of the initial treatment. In May, treatments were repeated for the browsed (2 browsed) and manually treated (2 manual) plots. Treatment procedures were the same as before except that 13 goats of 25 kg browsed for 16 days. Both browsing treatments were applied before coppice growth had grown out of reach of the goats.

At the end of the growing season (August 1983), total production was determined for each stump using the double sampling procedure described earlier. The amount of material removed from each stump during the treatments was added to season-end biomass to estimate total production for the season.

Coppice was allowed to grow undisturbed through the 1984 growing season. At the end of the season, coppice growth was cut from surviving stumps using the same harvesting procedure as in 1983.

Stem weight, leaf weight, combined stem and leaf weight, and leaf/stem biomass ratio were compared by analysis of variance using the SAS statistical package. Separate analyses were done for 1983 total production, 1984 total production, and the sum of 1983 and 1984 production. Homoscedasticity was tested using Cochran's test (Guenther 1964). Fisher's protected LSD was used to compare means at

alpha = .05. Mortality at the end of two years was analyzed as a comparison of proportions using X^2 as described by Fleiss (1981).

Results

Mortality. All sabià and catingueira survived regardless of treatment (table 7). Defoliated (browsed or recut) marmeleiro and pau branco experienced significantly more mortality than the untreated controls (table 8). Two manual treatments caused more mortality than browsing for marmeleiro. Pau branco mortality was not significantly different for the two treatment groups. Too few marmeleiro survived to provide reliable data on biomass production.

1983 Total Biomass Production. All species had similar patterns of stem production. Trees manually treated once or twice produced comparable amounts of stem biomass (table 9). Undefoliated trees, and those which were browsed by goats produced significantly more stem material than the manually treated trees. Only in the case of pau branco did undefoliated plants produce significantly more stem biomass than the browsed plants.

Leaf production by catingueira and sabià was similar under all treatments. Catingueira produced more leaves when browsed than when undefoliated and manual treatment reduced leaf biomass. All defoliation treatments reduced sabià leaf production. However, none of these effects were statistically significant. Pau branco followed the same pattern, but production by undefoliated plants was significantly greater than defoliated plants and browsed plants produced significantly more leaf than manually treated plants. There was no

Table 7. Mortality associated with species and defoliation treatments of four caatinga species of northeast Brazil.

Species	Defoliation Treatment	Total Trees	Trees Killed
catingueira	2 manual	31	0
	2 browsed	18	0
	undefoliated	30	0
sabià	2 manual	29	0
	2 browsed	18	0
	undefoliated	30	0
marmeleiro	2 manual	10	7
	2 browsed	6	1
	undefoliated	11	1
pau branco	2 manual	30	3
	2 browsed	18	5
	undefoliated	30	0

Table 8. Comparison of proportions of dead trees associated with species and defoliation treatments in northeast Brazil.

Comparison	X^2 .05	X^2 diff.
all catingueira and sabià vs all marmeleiro and pau branco	3.84	27.10
all marmeleiro vs all pau branco	3.84	7.87
defoliated vs undefoliated pau branco	3.84	5.57
2 manual vs 2 browsed pau branco	3.84	2.56
defoliated vs undefoliated marmeleiro	3.84	4.90
2 manual vs 2 browsed marmeleiro	3.84	4.26

Table 9. Mean 1983 biomass production (g dry weight) of individual trees, of three caatinga species in northeast Brazil.

Defoliation Treatment	Stem Weight (n)	Leaf Weight (n)	Total Weight (n)	Leaf/Stem Biomass Ratio (n)
		Catingueira		
undefoliated	391 a (30)	341 a (30)	731 a (30)	.9127 a (30)
browsed	358 a (14)	393 a (14)	751 a (14)	1.4337 a (14)
1 manual	191 b (17)	250 a (17)	442 b (17)	1.2809 a (17)
2 manual	129 b (32)	207 a (32)	336 b (32)	1.6872 a (32)
		Pau Branco		
undefoliated	744 a (30)	442 a (30)	1176 a (30)	.6719 b (30)
browsed	442 b (17)	265 b (13)	702 b (13)	.6385 b (13)
1 manual	161 c (18)	193 c (18)	354 c (18)	1.2520 a (18)
2 manual	143 c (30)	181 c (30)	324 c (30)	1.2964 a (30)
		Sabià		
undefoliated	297 a (31)	212 a (31)	509 a (31)	.7419 c (31)
browsed	228 a (16)	167 a (15)	397 ab (14)	.7869 c (14)
1 manual	132 b (14)	151 a (14)	283 b (14)	1.1673 b (14)
2 manual	121 b (24)	164 a (25)	289 b (21)	1.4215 a (24)

For each species values within a column followed by the same letter are not significantly different ($P < .05$) by Fisher's LSD test.

significant difference in leaf production between pau branco manually treated once or twice.

Analysis of total weight (stem plus leaf) did not differ from stem weight alone except in the case of browsed sabià, which did not produce significantly more than the manually treated trees nor less than the undefoliated ones.

The leaf/stem biomass ratio of browsed and control plants did not differ for pau branco and sabià, but these ratios were significantly less than the ratio for manually treated plants. Only sabià exhibited any difference between the leaf/stem ratios of the two manually treated groups, with the trees treated twice having a higher ratio.

Inevitably some regrowth occurred during the browsing treatments. The goats showed a strong preference for new growth, eating it as soon as it was detected. This minimizes the importance of regrowth as a source of error in estimating total production.

1984 Total Biomass Production. At the end of the 1984 growing season, non-defoliated trees of all species had more stem material than the browsed or twice recut trees (table 10). Data were not available from the trees which had been recut only once. There were no significant differences in stem production between trees browsed twice and those which were manually treated twice although in all cases the manually treated trees produced less than the other treatments.

Catingueira leaf production was less under defoliation treatments, but the decline was not significant at the .05 level. Undefoliated pau branco had significantly more leaf material than treated trees. Manually treated sabià produced significantly less leaf than

Table 10. Mean 1984 biomass production (g dry wt) of individual trees, of three caatinga species in northeast Brazil.

Defoliation Treatment Ratio	Stem Weight (n)	Leaf Weight (n)	Total Weight (n)	Leaf/Stem Biomass (n)
		Catingueira		
undefoliated	2851 a (20)	568 a (20)	3419 a (20)	.2261 a (20)
browsed	1414 b (13)	431 a (13)	1845 b (13)	.4819 a (13)
2 manual	1102 b (21)	480 a (21)	1582 b (21)	.4476 a (21)
		Pau Branco		
undefoliated	3385 a (20)	957 a (20)	4342 a (20)	.2599 a (20)
browsed	1408 b (9)	478 b (9)	1886 b (9)	.3605 a (9)
2 manual	1067 b (19)	461 b (19)	1528 b (19)	.7405 a (19)
		Sabiá		
undefoliated	3454 a (22)	561 a (22)	4015 a (22)	.1887 b (22)
browsed	1692 b (13)	440 ab (13)	2132 b (13)	.2857 a (13)
2 manual	1130 b (18)	222 b (18)	1350 b (18)	.2674 a (18)

For each species values within a column followed by the same letter are not significantly different ($P < .05$) by Fisher's LSD test.

the controls. Leaf production by browsed sabià was intermediate between the control and manually treated groups.

Total biomass production is dominated by the stem fraction and follows the same pattern as stem biomass production.

The leaf/stem biomass ratios for 1984 were considerably lower than 1983. Sabià was the only species where the increased leaf stem ratio carried over to the second year. In 1984 there was a significant difference between treatment groups: control trees had a lower ratio than defoliated trees. Similar trends exist for catingueira and pau branco.

1983-1984 Combined Biomass Production. The effect of treatment is less apparent when total production over the two-year period is examined (table 11). Undefoliated pau branco and catingueira produced more stem material than either manually defoliated or browsed trees. There was no significant difference in stem production between browsed and manually treated stumps, although mean stem production by manually treated stumps was always less. Undefoliated sabià produced more stem material than manually treated sabià, and production by browsed trees was intermediate between the two.

Sabià leaf production did not vary significantly with treatment. Undefoliated pau branco produced more leaf than defoliated pau branco. There was no significant difference between undefoliated and browsed catingueira. Manually treated catingueira produced less leaf than the undefoliated or browsed trees. For all species, there was a non-significant tendency for undefoliated plants to produce more leaf than browsed plants, which produced more than manually treated plants.

Table 11. 1983-1984 Combined biomass production (g dry wt) of individual trees of three caatinga species in northeast Brazil.

Defoliation Treatment	Stem Weight (n)	Leaf Weight (n)	Total Weight (n)
	Catingueira		
undefoliated	2882 a (19)	981 a (19)	3863 a (19)
browsed	1860 b (10)	843 a (9)	2822 b (9)
2 manual	1251 b (21)	645 b (21)	1896 b (21)
	Pau Branco		
undefoliated	3598 a (20)	1448 a (20)	5046 a (20)
browsed	1940 b (8)	699 b (6)	2335 b (6)
2 manual	1161 b (19)	609 b (19)	1770 b (19)
	Sabià		
undefoliated	3408 a (22)	768 a (22)	4177 a (22)
browsed	1953 ab (11)	572 a (10)	2250 b (9)
2 manual	1379 b (14)	405 a (15)	1791 b (14)

For each species values within a column followed by the same letter are not significantly different ($P < .05$) by Fisher's LSD test.

Total production followed the same pattern as stem production, and in all cases was significantly greater for controls with a non-significant tendency for browsed plants to produce more than manually treated plants.

Discussion

One objective of this study was to determine if removal of coppice growth kills coppicing stumps. Only those species which are not normally browsed by goats (marmeleiro, pau branco) experienced significant mortality. The more palatable species (catingueira and sabià) have apparently adapted to browsing sufficiently to survive cutting and removal of coppice growth twice within a year.

All four species experience regular insect defoliation. Caterpillars often strip entire trees early in the rainy season and grasshoppers consume large amounts of leaf material late in the dry season, but even severe insect outbreaks are not reported to cause tree losses in this area. Both intact and coppicing trees are subject to insect feeding while only very young, or coppicing trees are accessible to browsing livestock. A major difference between insect feeding and livestock browsing is that insects rarely attack stems and twigs, while goat browsing and manual recutting removes stem material and associated buds. Carbohydrates contained in the stems that are lost during browsing are available for regrowth following insect defoliation. This might account for the fact that goat browsing apparently results in greater mortality than insect feeding.

The idea that removal of coppice might result in compensatory growth exceeding that of the undefoliated group was not supported by

these results. In 1983, production by browsed catingueira and sabiá was statistically equivalent to production by the undefoliated stumps. Manually treated trees produced significantly less stem material. Leaf production was less affected by defoliation than stem production, although this proved to be short-lived, probably due to the tendency to replace leaf material before stem. By 1984, stem and leaf production by the undefoliated stumps exceeded that of all treatment groups. This suggests that severe defoliation cannot be used to stimulate increased forage production.

Browsing and manual removal of regrowth occur very differently, the first incrementally over time, and the latter instantaneously and completely. Browsing, particularly late in the season, tends to leave short stubs of stem attached to the stump. These stubs contain many buds and sprout rapidly. Manual treatment removes the sprout level with the stump, and although regrowth tends to be concentrated in the vicinity of the scar, it is slower to appear than on the browsed stumps. In contrast, browsing causes more damage to the bark which, especially in the case of catingueira, is often consumed. Total biomass production over the two-year period was not significantly affected by these differences, although there was a consistent pattern of reduced production by the manually treated stumps.

The most striking difference between the browsed and manually treated stumps is that in 1983, the browsed stumps leafed out again during the dry season. None of the manually treated stumps produced regrowth during the dry season. Thus, leaf production by the browsed plants is actually underestimated. Some of these leaves were retained and included with 1984 leaf production, but others were shed during

the rainy season and not accounted for in the biomass data. This was not judged to be a serious problem in that the amount of material involved would not significantly alter the results. While not statistically important, biologically this occurrence has implications which may constitute the most important difference between manual removal of coppice and browsing. This will be discussed in detail in the chapter on the phenology of coppice growth.

It is clear that not all caatinga tree species respond similarly to removal of regrowth from the coppicing stump. As noted earlier, sabià and catingueira are more tolerant of repeated defoliation than are marmeleiro and pau branco. Furthermore, differences exist between the response of these two more sensitive species. Differences between species can be exploited when managing the regenerating caatinga stand. The density of pau branco and marmeleiro in the regenerating stand can be controlled through defoliation of coppicing stumps, reducing competition with the more desirable forage species. Trees producing usable wood (sabià and some pau branco) could be cut with high stumps to put regrowth out of reach of browsers. Leaves could still be consumed when abscised, without risk of deforming woody growth.

Coppicing affects palatability as well as accessibility as forage. Green coppice of catingueira was consumed although mature plants of this species are not normally browsed when green. Coppice growth of marmeleiro and pau branco were readily browsed even though mature plants of these species are rarely browsed. If access to marmeleiro and pau branco coppice is allowed while it is palatable, total forage production will be increased through the addition of these species to

the forage pool. It is not clear if dried leaves of marmeleiro and pau branco coppice are palatable. Those species which are palatable when dry (catingueira and sabià) could be cut with high stumps, or allowed to grow out of reach in order to defer their production for dry season use.

Results of this study support the idea that regenerating caatinga stands can be manipulated to achieve specific management objectives for different woody species and different woodland products.

CHAPTER VI

THE ABSCISSION PHENOLOGY OF COPPICE GROWTH

During the course of the biomass studies, unexpected but dramatic changes in leaf fall phenology were observed. As the 1983 dry season began, it was apparent that coppicing stumps were retaining leaves longer than uncut trees of the same species. If coppice growth remains green substantially longer than other woody plants on a site, this could have important implications for balancing seasonal forage supplies, manipulating regrowth, and understanding the physiology of the coppicing stump. With this in mind, observations of leaf fall phenology were then incorporated into the study.

What follows is a description of observed changes in the abscission phenology of coppice growth with a discussion of possible correlations with environmental conditions and implications for managing the caatinga.

Methods

Phenological observations began in July of 1983 in both Sobral and Quixadà. Abscission was well underway by uncut trees of all deciduous species on both sites. Treatments examined in Quixadà included early and mid-dry season cuttings, and early and late wet season cuttings. In Sobral, treatments examined included early and mid-dry season cutting, early wet season cutting, removal of coppice growth once and twice, browsed coppice, and high (60 cm) and low (10 cm) stumps. None of the trees cut in the late wet season had coppiced. Uncut trees were also observed at both sites. Species observed in Sobral included catingueira, marmeleiro, pau branco, and

sabià. In Quixadà, catingueira, marmeleiro, and sabià were observed. Jurema preta was excluded because it is evergreen.

Observations were made on all three replications of each treatment at each site. These observations were repeated approximately every two weeks until all trees had produced a new leaf crop at the beginning of the 1984 rainy season. The procedure involved examination of every marked tree of each species. Data recorded included the percentage of foliage remaining (in intervals of 5%), where in the coppice clump leaves remained and what color these leaves were. Estimations of remaining foliage were based upon recent experience in measuring and/or harvesting the 1200 coppicing stumps described in earlier chapters. Only observations on the date at which leaf fall was completed are reported, although information on remaining leaf location and color were used in interpreting leaf fall patterns and evaluating their implications for forage production. Because there were rarely more than six trees of a species in each replication, the data are not suitable for statistical treatment, but are summarized and reported as observations.

Leaf fall is hastened by exposure to wind. Brisk winds are common during the dry season and it was observed that trees on exposed sites tended to lose leaves faster than those sheltered by adjacent uncut caatinga stands. To accommodate this, observations were summarized as the last date on which trees of a species retained leaves in two of the three replications. Because it is not unusual for a few dry leaves to persist on a plant through the dry season, abscission was considered complete when less than 5% of the foliage remained and that foliage was dry and brown.

The date at which abscission was considered complete was plotted for each species, treatment, and site. A difference of two weeks or more between any two groups was considered significant. This is based upon the assumption that an additional two weeks of access to green forage during the dry season would be beneficial to livestock.

Results

Sobral Site. The most striking observation was the fact that stumps of all four species whose coppice was browsed began to coppice again after browsing was halted late in the wet season. Coppice continued to appear and grow through the month of August. Although some of these leaves were abscised late in the dry season, none of this coppice growth ever shed all of its leaves before the rainy season began (figure 3). Coppice regrowth on browsed sabià retained 80% of its leaves during the dry season.

Uncut sabià were leafless when phenology observations began on July 25. Within 25 days, coppice on sabià cut in the early and mid-dry seasons completed abscission as did coppice on high stumps and stumps whose coppice had been manually removed once (figures 3 and 5). Coppice on sabià cut early in the wet season and on low stumps retained some leaves until August 31 (figure 4).

Abscission by intact catingueira was complete by August 16. Coppice on catingueira cut in the early dry season, early wet season, high stumps, and stumps whose coppice was manually removed once were leafless by August 31. Coppice on low stumps retained leaves until September 28. Coppice on catingueira cut in the mid-dry season had some leaves until October 1 (figure 4).

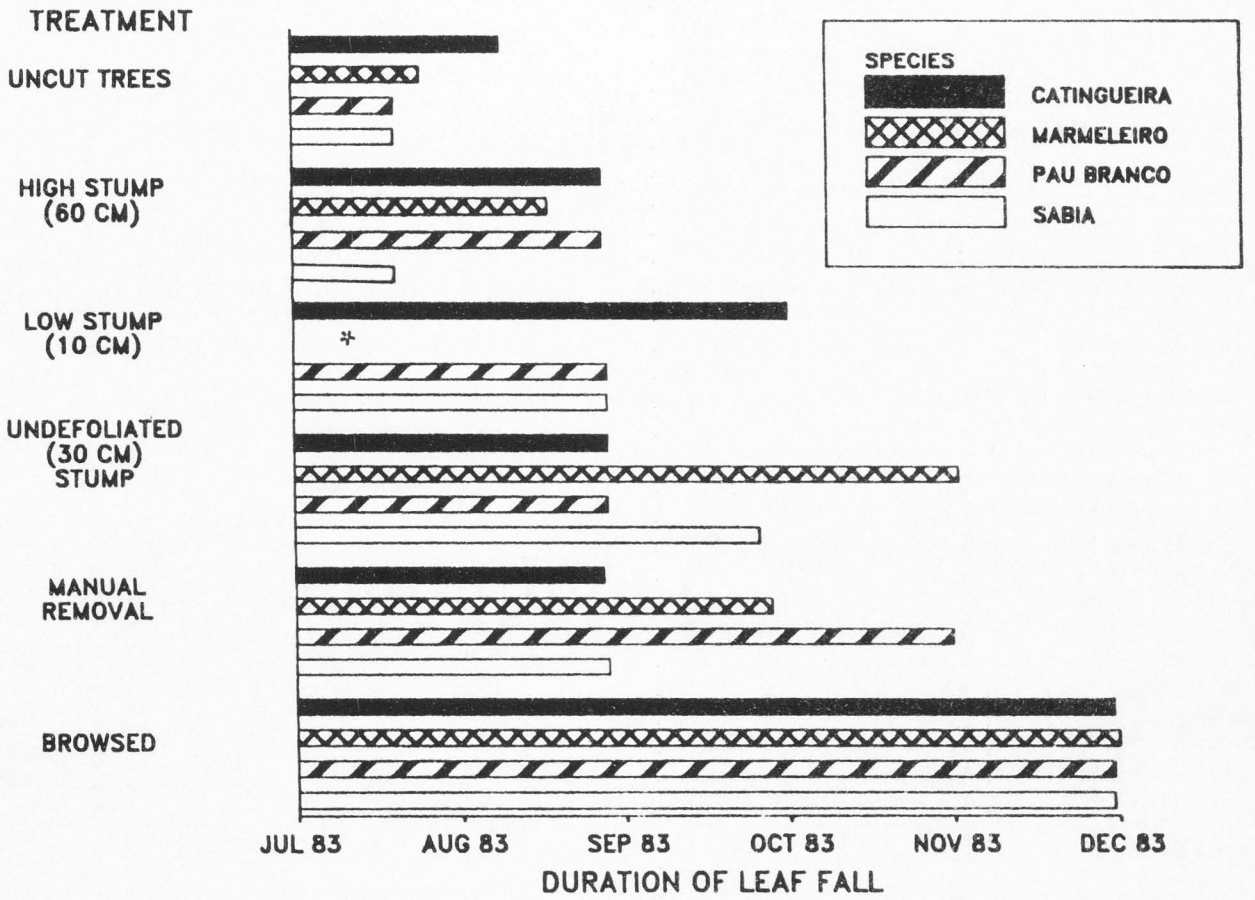


Figure 3. Effect of defoliation and stump height on leaf fall, Sobral 1983.

*Insufficient data available.

Marmeleiro in undisturbed stands were leafless by July 25. Early dry season coppice completed leaf fall by August 28. Coppice from manually defoliated marmeleiro retained leaves until September 28. By October 18, the early wet season coppice was leafless. Mid-dry season coppice completed abscission by November 2 (Figure 4).

Uncut pau branco were also leafless by July 25. Coppice growth on high pau branco stumps and stumps cut in the mid-dry season completed abscission by August 28. Low stumps retained leaves until September 28. Early wet season coppice was the next to lose its leaves, by October 16. Coppice on manually defoliated stumps retained some leaves until November 2 (Figure 4).

Quixadà Site. There were no discernible differences in the abscission phenology of uncut marmeleiro and marmeleiro cut during different seasons. However, the abscission phenology of coppicing catingueira and sabià was affected by the season in which the trees were cut (Figure 5).

Uncut catingueira and coppice growth from catingueira cut in the mid-dry season were leafless by August 16. Coppice growth on catingueira cut in the early dry season and at either time in the wet season retained some leaves until August 31 (Figure 5).

Uncut sabià and coppice growth on sabià cut in the early dry season and early wet season were also leafless by August 16. Trees cut in the mid-dry season produced coppice which retained some leaves until August 31. Trees cut late in the wet season produced very little regrowth, but leaves were retained on that regrowth until October 18, approximately two months longer than uncut trees.

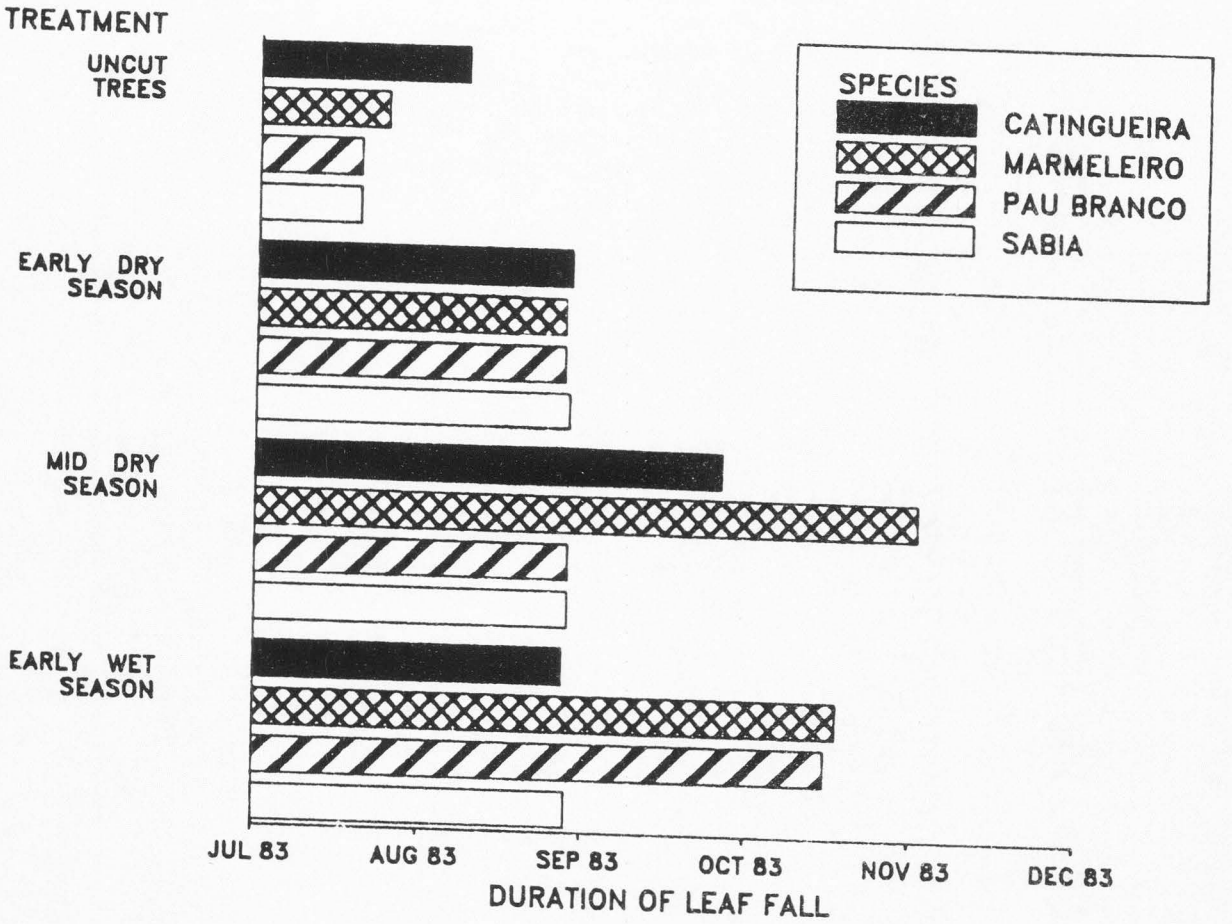


Figure 4. Duration of leaf fall in Sobral during 1983.

Comparison Between Sites. The species and treatments which were present on both sites (sabià, catingueira, and marmeleiro; cut in the early dry, mid-dry and early wet seasons) did not behave similarly on both sites. In general, there was much less variability in phenology in Quixadà. Uncut trees in Sobral completed leaf fall earlier than uncut trees in Quixadà. In Sobral, catingueira coppice from all cutting periods retained leaves longer than uncut trees, but only early wet season cutting increased leaf retention in Quixadà. Marmeleiro leaf retention in Sobral was maximized by cutting in the mid-dry season although all cutting treatments increased the duration of leaf fall compared to the intact trees. In Quixadà, marmeleiro abscission phenology was not affected by cutting in any season. In Sobral, sabià leaf fall was extended by slightly more than a month by cutting at any time, while in Quixadà only late wet season cutting delayed sabià leaf fall.

Discussion

These results support the observation that coppice growth can, under some conditions, retain foliage longer than mature trees. Although there were significant differences in the time of leaf retention by coppice produced under different treatments in Quixadà, the difference did not exceed one month. In Sobral, varying the time at which the parent tree was cut prolonged leaf retention by subsequent coppice growth by as much as 70 days and browsing stimulated regrowth which remained on the plants throughout the dry season. It is unclear why such differences would exist in the behavior of a species cut during the same season at the two different sites. Environmental differences may provide an explanation.

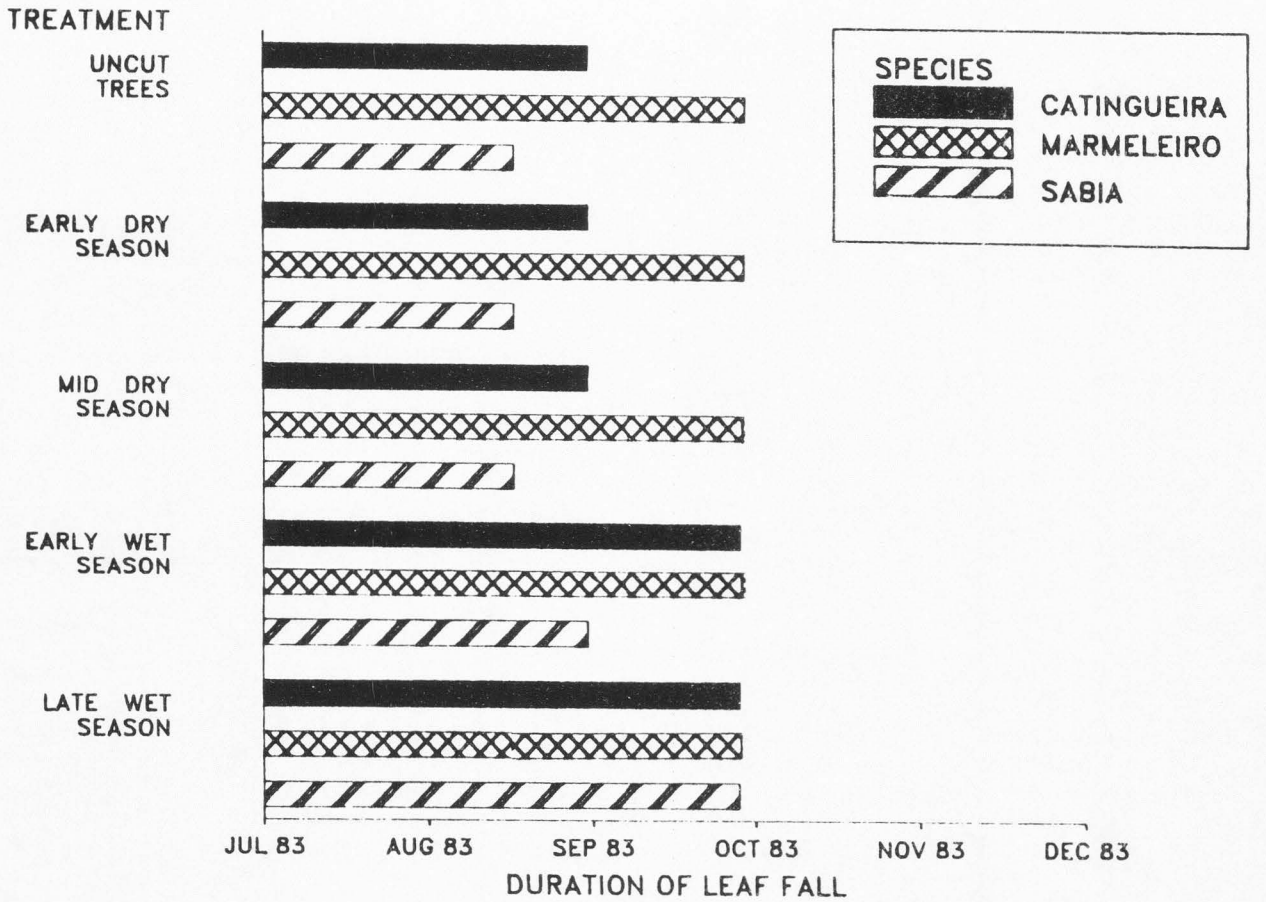


Figure 5. Duration of leaf fall in Quixadà during 1983.

Because moisture stress is thought to trigger abscission, differing rainfall patterns at the two sites might explain the observed differences in phenology. In 1983, rainfall in Sobral was 59% of average, while in Quixadà it was only 31.5%. The rainy season in Sobral ended in June with May and June precipitation equalling 43.1 and 0.6 mm, respectively. In Quixadà, rains ended in May with a monthly total of 24.5 mm. Conditions in Quixadà were considerably drier in 1983 than were conditions in Sobral, perhaps causing the trees in Quixadà to suffer greater moisture stress than their Sobral counterparts. Under these conditions, coppice growth in Quixadà may have been precluded from exhibiting the phenological variation seen in Sobral. The literature suggests that we could expect accelerated abscission in Quixadà because of increased production of abscisic acid as moisture stress intensified (Larson 1956). In actuality, uncut trees in Quixadà retained leaves considerably longer than intact trees in Sobral, suggesting that drought inhibits abscission in intact trees in this region.

It is not surprising that high stumps (60 cm) retained leaves for less time than lower stumps (10 cm and the 30 cm mid-dry season stumps). Coppice shoots on high stumps grew taller and were exposed to both desiccation and the mechanical force of the wind. Low stumps of pau branco and sabià retained leaves longer than 30 cm stumps. This may be due to the sheltering effect of taller surrounding vegetation.

An intriguing question raised by these results is how stumps whose coppice growth had been browsed were able to produce new shoots during the dry season and retain foliage on those shoots until the

next rainy season. In the caatinga, trees were observed to leaf out within hours of a rain of 45 mm whether that rain occurred in January (the normal time) or as early as November. Alvim (1964) and others state that bud break is tied to the beginning of the rainy season. The fact that trees cut during the dry season and coppicing stumps manually stripped of coppice shoots late in the wet season did not produce new growth until the following rainy season supports this contention. However, defoliation removes auxin producing tissue and reduced auxin levels stimulate coppice shoot production (Smith 1962). As coppice shoots appear, auxin production increases and high auxin levels are correlated with delayed leaf abscission (Addicott 1978). This scenario could account for the browsed stumps coppicing out of season and retaining those leaves, but it does not explain why manually treated stumps did not respond similarly.

Coppicing requires the presence of buds capable of producing new shoots. The trees cut in this study produced coppice growth from suppressed buds formed when the trees were seedlings. Likewise, coppice shoots produce numerous suppressed buds during their growth. Browsing removes the shoot tip, stimulating development of any suppressed buds remaining on the shoot. The second browsing treatment was less intense than the first, leaving a number of short stubs on the stumps. These stubs probably contain suppressed buds. In contrast, the manual treatments removed all coppice shoots flush with the stump including the suppressed buds produced during the shoot's growth. Both times manually treated stumps resprouted, the majority of the sprouts appeared on or close to the site of previous shoots. These could be adventitious, arising from buds which appeared following the

injury, or could be produced by suppressed buds formed either during the growth of the original tree or the coppice shoot. The shoot's origin can only be determined through examination of cross sections of the parent stump at the point of origin of the bud, a procedure that was not possible in this case. However, Hook and DeBell (1970) have observed that water tupelo, which produces coppice shoots from both adventitious and suppressed buds, does not produce both shoot types simultaneously. Adventitious shoot production follows the appearance of shoots derived from suppressed buds. If this were the case for the species observed in the caatinga, then perhaps the browsed stumps were able to produce coppice from the suppressed buds remaining on the stubs of the browsed shoots. Manually treated stumps lacking these stubs would not have time for adventitious buds to form and extend before the rapidly advancing dry season created unfavorable growing conditions.

These hypotheses assume that environmental conditions are favorable for plant growth early in the dry season. Yet, the very process of abscission is considered evidence of increasingly unfavorable conditions (Addicott 1978). During the preceding rainy season, stumps whose coppice was browsed produced less total foliage and were foliated less time than unbrowsed stumps. If the browsed stumps removed less moisture from the soil prior to the beginning of the rainy season, they might be able to utilize this "extra" water to coppice one last time late in the season. However, the shallow nature of these soils, combined with their low organic matter content, severely limits their water retention capacity regardless of water demand. Nor were there large differences in the amount of plant biomass and the time it

was present on the plots receiving the different defoliation treatments. These facts suggest that available moisture is not sufficient to explain the observed differences.

Another hypothesis is that browsing and manual defoliation each interfere with the interplay of growth regulators in the coppicing plant in a slightly different fashion. Because a number of variables influencing abscission phenology were not examined, no precise explanation can be offered for the results observed. However, these results do have interesting implications for caatinga management.

An obvious question is: Can abscission phenology be manipulated to improve the dry season forage supply? Because the length of the dry season is variable, the producer never knows how long he must be able to provide feed for his animals until the next rainy season. Any method of effectively shortening this period of scarcity and uncertainty merits consideration. Diet studies show that leaf litter consumption by sheep and goats increases as the dry season progresses and dried herbaceous forages are depleted (Pfister 1983, Kirmse 1984). The forage supply is not limited early in the dry season, but may become extremely limited by the end of a normal dry season, and critically inadequate in times of drought. Manipulating the abscission phenology of coppice growth could affect forage quantity, quality, and seasonal availability. In the defoliation trials, it was observed that green coppice growth of marmeleiro and pau branco was readily browsed by goats even though foliage from intact trees of these species is not normally browsed. If delaying the abscission of leaves of these species on coppicing trees maintained their palatability, then the forage supply would be increased. The forage quality of tree

leaves declines as the leaves dry and begin to decompose (Kirmse 1984). Leaves may retain their nutritional quality longer if they are retained on the tree longer, thus if eaten from the tree, leaves may be of better quality than those which have already been shed. Alternatively, if deferred until the leaves are finally shed, their quality may have declined slightly but they would become available at a time when other forage resources are becoming depleted.

These implications warrant further investigation of the phenomenon of delayed abscission phenology. Specific questions should include: How much green forage can be produced how late into the dry season? Do phenological changes persist, and if so, for how long? And what are the nutritional properties of this browse?

CHAPTER VII

PROSPECTS FOR MANIPULATING COPPICE GROWTH TO IMPROVE CAATINGA MANAGEMENT

Effects of the Current Management System

Taken together, the results of this study have several implications for improving management of the caatinga. As a basis for comparison, I will first review the effects of the current management system. Caatinga stands are usually clearcut during the dry season. Dry season cutting will maximize regrowth of most caatinga species and no stump mortality is expected. When the rainy season begins, all of the stumps will coppice and will soon form a low, dense canopy. Herbaceous plants will have germinated and be growing in the spaces between coppicing stumps and, often, up through the coppice. Even in unusually dry years, the regenerating stand will become a dense tangle of woody regrowth and herbaceous plants. If livestock are excluded, seedlings of sabià, mororo, and other palatable woody species will appear. If livestock have been feeding in the stand, seedlings of the more palatable species will be eliminated and coppice growth will be browsed to a degree commensurate with its relative palatability and the number of animals present.

Because no evidence of competition-caused mortality of coppicing stumps was observed in this study, the total number of woody plants in the stand will probably equal or exceed the number present before cutting and the species composition will be almost identical. When the dry season begins, coppice growth will retain its leaves a month or more longer than will trees in uncut stands. Thus total herbaceous

production will have increased severalfold and tree leaf litter production will have declined relative to uncut stands (Kirmse 1984, Schacht 1986).

During the second year of regrowth, coppice clumps will continue to grow taller and wider, but foliage will be concentrated on the outer edges of the clump, suggesting competition for light and water. Some of the heavier branches may break off the stump, apparently unable to support the weight of their own water soaked foliage. Still no mortality will occur among the coppicing stumps, even when they are subjected to heavy insect defoliation, which typically occurs early in the rainy season. As the woody canopy closes, there will be less herbaceous growth, and by the end of the second year, many of the herbaceous species, and probably the seedlings of the less tolerant woody species, will be shaded out by woody regrowth exceeding 3 m in height. Most of the coppice foliage is out of reach of browsers. Some mortality may have occurred among stumps of pau branco and marmeleiro if they were heavily browsed several times during the year. Abscission will again be somewhat slower than in intact stands. Total herbaceous production will have declined from the first year but will still exceed that of an uncut stand, and while leaf litter production will have increased, but will still not equal that of the uncut stand (Schacht 1986).

By the third year the stand will appear similar to its original state, except that the trees will be shorter and multi-stemmed rather than single-stemmed or several-stemmed. Herbaceous production will remain greater than in uncut stands but woody leaf litter accumulation will have returned to levels produced by intact caatinga.

From the range manager's point of view there are several problems with this management scheme: 1) the regenerating stand contains the same proportion of non-forage species as the original stand, and they compete with more desirable species; 2) dry season forage production is not increased; 3) temporary increases in wet season forage production will aggravate existing imbalances between wet season and dry season forage supply; 4) disturbance may cause an increase in the density of marmeleiro, a very invasive undesirable species; and 5) frequent cutting cycles may lead to increased soil erosion, loss of nutrients from woody materials, and a permanent decline in site productivity (Ramos and Marinho 1980).

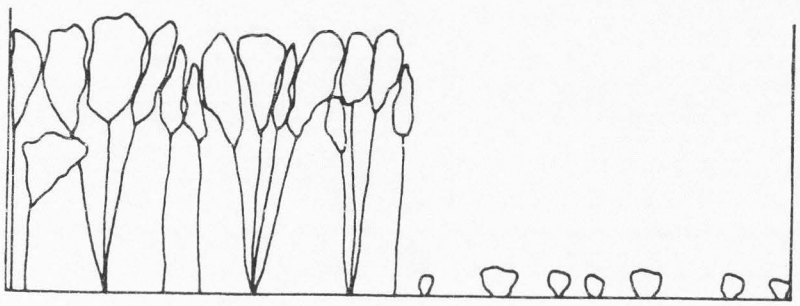
Ideally, wet and dry season forage supplies should be more closely balanced, the desirable wood and forage producing species should be favored over less valuable species, and the situation should be sustainable without risk of environmental degradation. Information gained from this study can contribute to achieving these goals.

An Alternative Scenario

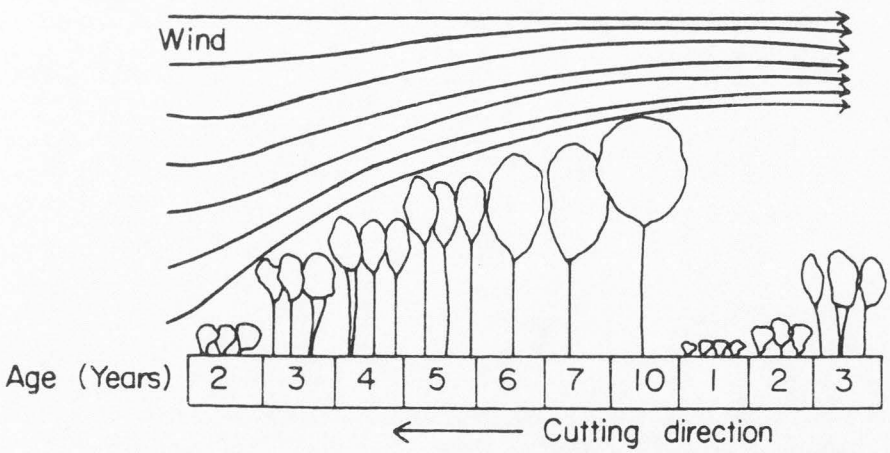
Balancing the forage supply requires enough available forage to meet the animals' needs during every month of the year. This is most efficiently achieved by increasing production during periods of scarcity and/or preserving some forage from more productive periods for use when forage is scarce. Stocking rates cannot exceed the forage available during the leanest month in the forage production cycle. The farmer who has only as many animals as can be adequately fed during the dry season wastes much of the wet season's abundant forage, because these herbaceous forages do not cure well (Kirmse 1984). In contrast, the farmer who has enough animals to utilize most of the wet

season production is unlikely to be able to maintain his herd during the dry season. However, the farmer in the northeast often does not have control over his rangeland, but lets his sheep and goats range in common with animals from other nearby farms on unoccupied lands held by absentee landowners (Primov 1984). Thus the farmer who stocks conservatively is no more likely to have adequate dry season forage than the farmer who overstocks, which creates an incentive to overstock. Managing the caatinga to increase dry season forage production relative to wet season forage production is a better alternative.

The current clearcutting system causes a dramatic increase in wet season forage production and a decline in dry season forage (leaf litter) production for at least two years after harvesting (Kirmse 1984, Schacht 1986). Woodcutting must continue because of the demand for fuelwood and construction materials, but clearcutting may not be necessary. A partial cutting scheme and uneven-aged management can produce a sustainable flow of forage and wood products without many of the problems associated with clearcutting (Figures 6-8). Selection cutting is a form of uneven-aged management that is already in use, in which only the most desirable trees are harvested and the rest of the stand is left intact (Queiroz 1985). Removing selected trees or groups of trees from the stand creates openings in which regeneration from coppice and seedlings, as well as increased herbaceous production may occur (Figure 6). Because leaf area in a stand with a closed canopy tends to be fixed (Long and Smith 1984, Bassman and Black 1984), the remaining trees will produce additional foliage to compensate for that lost from the trees removed. Thus total leaf litter production



A



B

Figure 6. Comparison of current even-aged management scheme (A), with strip harvesting (B) as suggested by Kirmse (1984). (Redrawn from Smith 1986.)

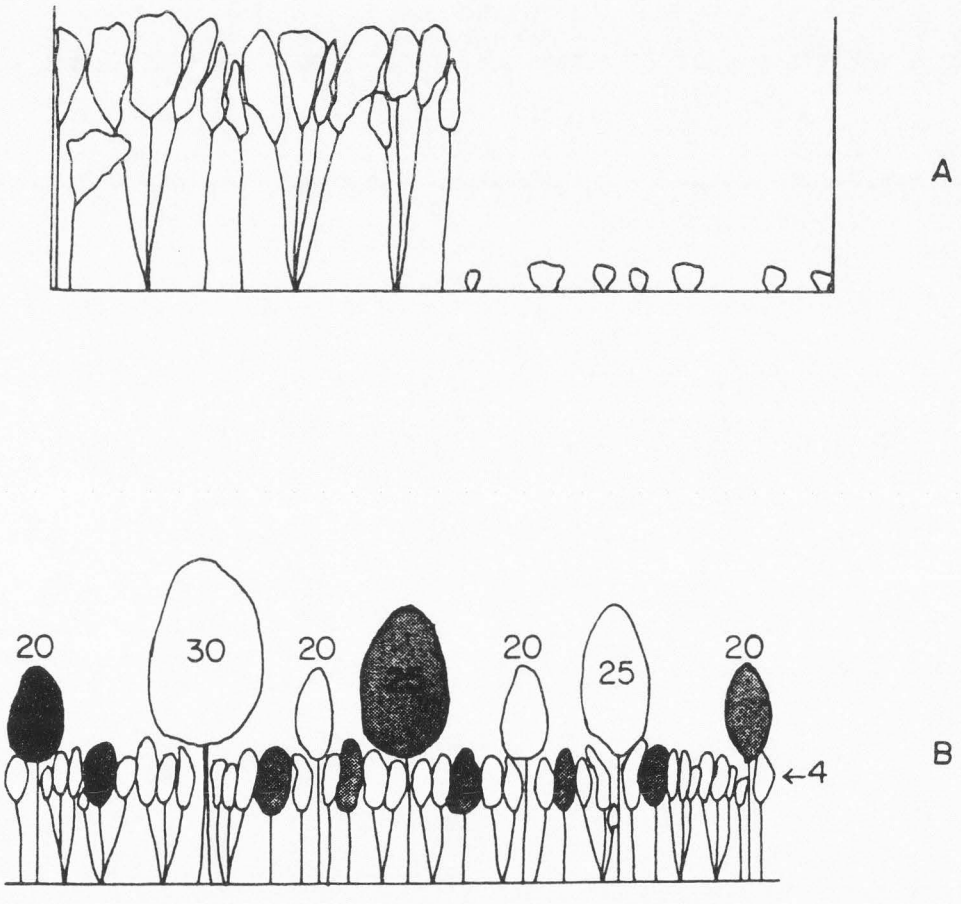
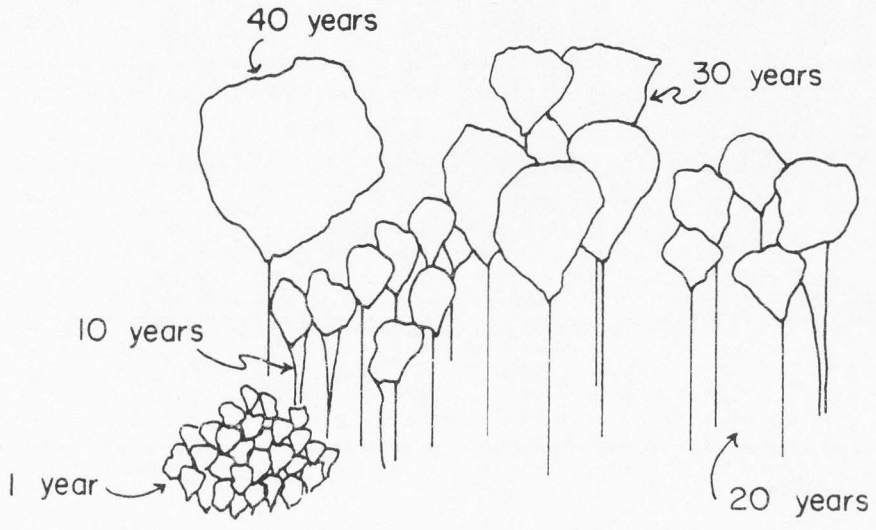
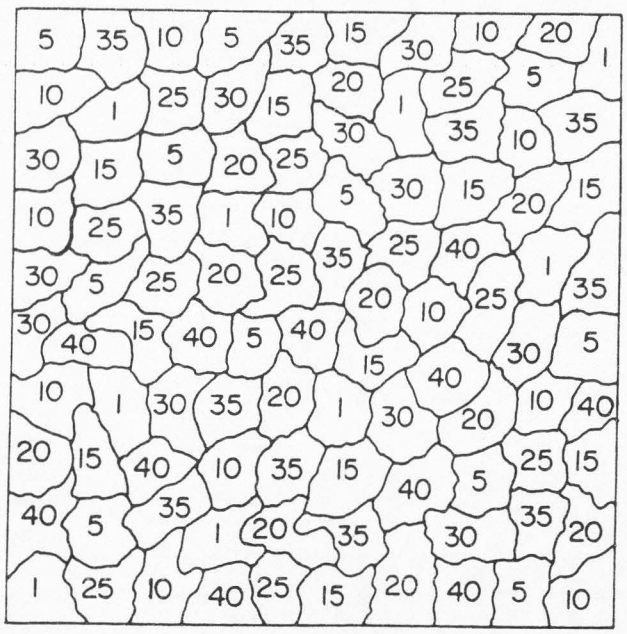


Figure 7. Comparison of current even-aged management scheme (A), with balanced, uneven-aged management (B). (Redrawn from Smith 1986.)



A



B

Figure 8. Schematic representation of single tree (A), and group selection (B) methods of managing an uneven-aged stand. (Redrawn from Smith 1986.)

could be maintained, while herbaceous forage production would increase in the openings and a steady flow of wood products would be produced.

To improve the quantity of palatable material in the leaf litter, harvest should be selective with regard to species and season of cutting. Species that do not produce desirable wood or forage should be thinned out of the stand during the late rainy season, when subsequent coppice production is minimal. If browsing animals have access to coppice growth, results of this study suggest they will find it palatable and through repeated removal of the coppice, may even kill stumps of marmeleiro and pau branco. If less than 50-60% of the canopy is removed, coppice production will be reduced (Schacht 1986) probably due to competition for light.

When desirable tree species are harvested, there are several ways of ensuring their persistence in the stand. The first is to cut during the dry season to maximize subsequent coppice production. If regeneration is intended for wood production, cutting the stump as high as possible, up to 1.6 m above ground, will put coppice shoots out of reach of browsing sheep and goats. If this is not practical, protecting the area from grazing for the duration of the first wet season after cutting will minimize browsing damage and by the second year of growth, most shoot tips will be out of reach. If the area is closed to grazing to protect coppicing trees, the forage produced will not be wasted because the area can still be grazed during the dry season. Early in the dry season, the dried herbaceous forages will still be abundant and relatively nutritious and if grazing is initiated then animals will concentrate on this forage source until it becomes scarce before turning to leaf litter and browse (Pfister 1983, Kirmse 1984).

Uneven-aged management would produce less widespread disturbance than the current system, and would create fewer opportunities for marmeleiro to increase and would reduce soil erosion. Restricting the size of the disturbed area enables rainfall to be intercepted and its force diminished before it hits the ground. Surface flow may be reduced when undisturbed areas remain.

Implementing these suggestions would require changes in wood harvesting methods. However, because all wood cutting is done manually and woodcutters are familiar with the species present, change is possible. Several different wage scales for woodcutters are currently used, the most common being payment for the volume of wood cut. Under this system, each woodcutter maintains a separate woodpile and every possible bit of wood is added to it. A second system involves payment per stem harvested and is most often used in selective harvest of timbers and posts. A flat hourly or daily rate is rarely used because it is thought to encourage laziness. It would be necessary to develop incentives for woodcutters to cooperate in changing the harvest procedure. Experiences in preparing the study area for this research demonstrate that this is possible, particularly when payment is on a per stem basis.

Pfister and Malechek (1986) have recommended removal of pau branco because it contributes a large quantity of unpalatable leaves to the annual leaf litter crop. This suggestion needs some qualifications. While pau branco is widely distributed, it rarely dominates stands as completely as in Pfister's study area, and it is a very valuable species for construction and furniture making. Indeed, woodcutters report that large, high quality pau branco are becoming scarce

because they are harvested too frequently and the coppice growth rarely has the straight form, or achieves the size required to produce boards or beams. Therefore, it is suggested that those trees with the potential to produce marketable timber be retained in the stand, while trees with poor form and many stems be eliminated. This would reduce the density of pau branco without drastically affecting the yield of valuable pau branco products. The possibility that cultural practices such as thinning coppice shoots could increase the marketable yield of pau branco should be investigated. Also, leaving sufficient pau branco to provide a leaf litter cover immune from browsing is recommended to protect the soil surface and add organic matter.

Sabià is the other prevalent species that produces valuable wood, primarily straight, rot resistant posts and poles. In contrast to pau branco, however, it has extremely palatable foliage. If the density of pau branco were reduced, sabià would be a good replacement. Sabià coppices well and endures heavy browsing, although this may delay production of marketable wood. Sabià reproduces readily from seed in cleared areas, but the seedlings are vulnerable to browsing and would need protection to become established. It is not known how long such protection would be needed, or if it would be necessary during the dry season when no green leaves are present to attract animals' attention to the plant.

Catingueira makes up a large percentage of most caatinga stands. It is unparalleled as a dry season forage producer because the foliage is palatable only very early in the rainy season or after it has been abscised in the dry season, just when additional forage is most needed. Coppice growth is palatable year-round and the plant tolerates

repeated defoliation of coppice growth. The hollow wood of catingueira is useful only for fuelwood. No major change in the management of catingueira is recommended; it can be cut as needed and allowed to regenerate from coppice. Stands that are dominated by catingueira might be improved by replacing some catingueira with sabià to increase the value of the wood produced.

Marmeleiro produces little usable wood or forage, except in the case noted earlier where it produces leaves following mid-dry season showers. Marmeleiro appears in dense stands following disturbances on some soil types (Queiroz 1985). It reproduces prolifically from seed and coppice, is resistant to slashing of regrowth, and may root sprout to form thick clumps. Every effort should be made to prevent its establishment or spread. Reducing the size of the area cut and frequent browsing or slashing of regrowth may help control this species. Further cautions might be to avoid clearing uninvaded areas near dense marmeleiro stands, limiting use of stands dominated by marmeleiro to grazing and very selective tree harvest, and avoiding clearing existing stands until some proven method of revegetation that excludes reinvasion is developed. This would not necessarily halt the spread of the species, but might slow it down, reducing soil loss and site damage, until some better form of control is found.

Jurema preta is a palatable forage species, but its contribution to the forage supply is limited by the small amount of foliage it produces and the fact that the foliage is often out of reach while on the tree and difficult to encounter once shed because of the leaflets' small size (1 x 5 mm). Because this is a pioneer species, very little opportunity would occur for establishment of new jurema preta if

uneven-aged management were implemented. This species gradually becomes decadent and dies out of closed stands. The wood is very valuable; I would recommend cutting it out of maturing stands before it becomes decadent and its wood value declines. Dry season cutting of jurema preta is preferred because the wood is not easily cut in the wet season when its water content is higher. An evergreen, it will coppice after dry season cutting, just when its foliage is most needed. Coppice growth would be accessible and palatable to browsers, and its use as forage is advised as the tree is unlikely to ever produce any more usable wood.

Areas for Further Research

These recommendations address small changes that can be made within the existing management scheme to improve dry season forage yields while maintaining supplies of other products. Other possibilities should also be investigated further. The first of these is the effect of fire on the vegetation and soils of the caatinga. Though burning is often included under current management, we know very little about its benefits and hazards. A second subject that needs further study is animal control. Presently, management options are limited by the lack of control of grazing animals (Primov 1982, 1984). Barbed wire fences are too expensive for most farmers; wood fences are time and labor intensive and require much maintenance. One possibility is herding, perhaps with the help of herding dogs. Most farms have several dogs, suggesting that having a working dog would be an acceptable idea. With or without dogs, herding has been used very successfully for managing small ruminants in much of the world. Sheep and

goats are already accustomed to being called in and penned nightly. A herding system could capitalize on this conditioning.

All of the suggestions made so far assume that no major changes will occur in the present management system. In reality, changes are being forced upon this system. The human population of the region continues to grow and places ever growing demands upon a finite resource base. Substantial efforts are being made to improve agricultural production, but to date, no efforts have been made to address the energy needs of the region. Traditionally, wood fires are used for cooking and industrial processes. Alternatives must be developed to meet these energy demands. Electricity and butane gas are being used in many homes, but their expense prohibits use by the majority of households. Biogas is unheard of. There are no good alternatives to wood products in construction. Bricks must be fired in wood burning kilns, and cement is very costly. Woodcutters have told me that both the extent and quality of the woodlands is declining. Because of the enormous demand for wood, the land clearing cycle is accelerating with presumed adverse effects on the vegetation, soils, and water.

A forest management program is needed to ensure a continuing supply of wood products. Forest management would also improve soil stability, water quality and yield, and, possibly, range conditions. Intensively managed plantations could meet the region's wood needs more efficiently than the current opportunistic use of the caatinga. Agroforestry systems could be developed to integrate production of food crops, fiber, wood, and forage. Many of the native tree species may be suitable for more intensive management, and the technology for managing multi-purpose forests in arid areas is developing rapidly.

Not only might this approach be useful in solving the northeast's natural resource management problems, but Brazil, through the efforts of EMBRAPA, is capable of becoming a world leader in this area. Agroforestry systems developed for managing the caatinga would have many applications worldwide in regions where this type of research is difficult, if not impossible, to conduct (NAS 1980). The infrastructure and the opportunity already exists for making rapid progress towards solution of these problems.

The Long Range Prognosis

The prospects for substantially improving small ruminant production on rangeland are not clear. Small ruminants are only one component of a complex mixed production system that is plagued by many problems (Primov 1982, 1984). Often sheep and goats are a low priority, making even minimal investments in their welfare difficult to justify (Primov 1985). Because animal production is combined with production of food crops for the household, conflicts frequently arise when livestock interfere with crops. Sending animals into the caatinga reduces the threat to crops but creates new problems. Range improvements such as fencing, water development, or vegetation management could improve range livestock production. However, if the owner of the livestock has no legal right to the land being grazed, he has no incentive to improve it. In fact, there is a disincentive: if the productivity of the land is improved, the landowner may decide to use it for cattle production, excluding the former user altogether (Primov 1984). Thus, land tenure is an important range management issue in northeast Brazil.

Human population is another large-scale issue that affects range management options. Carrying capacity, the idea that a given range can support only a limited number of animals, is a basic ecological principle which applies to human populations as well as animals. Certain inalterable factors--erratic rainfall, poor soils and drought prominent among them--limit the productivity of the Brazilian northeast. Degradation of land and water resources reduces productivity further. Yet the human population of the region continues to grow and, unable to meet their basic needs at home, many people from the northeast move to more urban areas, compounding massive problems there. It is unlikely that the natural resource base can be protected or improved under these conditions. The region will need ever-increasing assistance from outside to support its population, a difficult proposition given the nation's current economic problems. The alternative is to reduce the region's human population to a level that can be sustained by its natural resource base, an impossible goal. In this context, agricultural improvements are unlikely to bring about significant, long range improvements in the well-being of the rural people of the northeast.

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VITA

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WORK EXPERIENCE

Assistant Professor, Range Management. Department of Forestry and Range Management, Washington State University. Responsible for teaching undergraduate and graduate courses in Natural Resource Management and Range Management. Quarter-time research appointment in Range Management and Agroforestry. 1985 to present.

Research Associate, Department of Range Science, Utah State University. Assigned to the Brazilian National Goat Research Center. Worked with federal and state agricultural research organizations conducting research on goat foraging in native vegetation. Developed modifications of traditional land use practices designed to improve forage production. 1982-1984.

Teaching Assistant, Department of Range Science, Utah State University. Assisted with lecture, and conducted weekly field exercises in range vegetation analysis, for two semesters. Taught one section of "Natural Resources and Man's Future." 1980-1981.

Senior Range Manager, Idaho Department of Lands, Boise and Gooding, Idaho. Administered leasing of state lands and worked with livestock producers to increase the productivity of rangelands through grazing management and range improvements such as brush clearing and seeding. Appraised lands for sale. Worked with various state and federal agencies on cooperative land use planning, exchange of use agreements, land sale and exchange projects, reclamation and rehabilitation programs, and joint grazing plans. 1977-1980.

Range Manager, Idaho Department of Lands, Gooding, Idaho. Evaluated the condition and potential of state owned grazing lands. Arranged leases to optimize utility to the state's livestock industry, maintain or enhance range condition and insure a fair return to the state endowment fund. 1976-1977.

Project Leader, LANDSAT Winter Range Mapping Project, Idaho Department of Fish and Game. Developed vegetation classification scheme for ground truthing satellite data and worked with NASA and consultants to design a mapping procedure suitable for wildlife habitat inventory. 1976.

Assistant Timber Inventory Specialist, Idaho Department of Lands. Preliminary timber typing and selection of sites for field inventory. Collation and interpretation of field data and preparation of inventory reports and management plans. 1975.

EDUCATION

Ph.D. Range Management, Utah State University.
Dissertation: Factors affecting the sprouting response of woody caatinga species and their implications for improved caatinga management. 1986.

M.S. Range Management, Utah State University.
Thesis: A review of tropical and subtropical brush management techniques with special reference to northeast Brazil. 1982.

B.S. Wildlife and Fisheries Management, University of Idaho. 1974.

OTHER PROFESSIONAL EXPERIENCE

Range Management Consultant to University of Missouri Sociology Project, Bahia, Brasil. 1983.

Consulting Forage Specialist on Beef Survey team sent to Portugal by the U.S. Feed Grains Council. 1984.

Editor, Leaflets, the Agroforestry Consortium Newsletter 1987.

Secretary of the Agroforestry Consortium. 1987.

Membership Committee Chair, Idaho Section, Society for Range Management. 1979.

Committee for National Summer Tour, Society for Range Management, Pocatello, Idaho, 1979.

Entertainment Committee for the 38th Annual Meeting, Society for Range Management, Salt Lake City, Utah, 1985.

HONORS

Rangeman of the Year, Idaho Section, Society for Range Management, 1979.

Xi Sigma Pi Forestry Honorary

Phi Sigma Biology Honorary

PUBLICATIONS AND PRESENTATIONS

Hardesty, L. H. and J. H. Bassman. 1987. Institutionalizing range management's role in agroforestry systems. Proceedings 3rd International Rangeland Resources Development Symposium. Boise, Idaho.

Hardesty, L. H. 1987. Coppicing: using a forester's tool on rangelands. Rangelands (in press).

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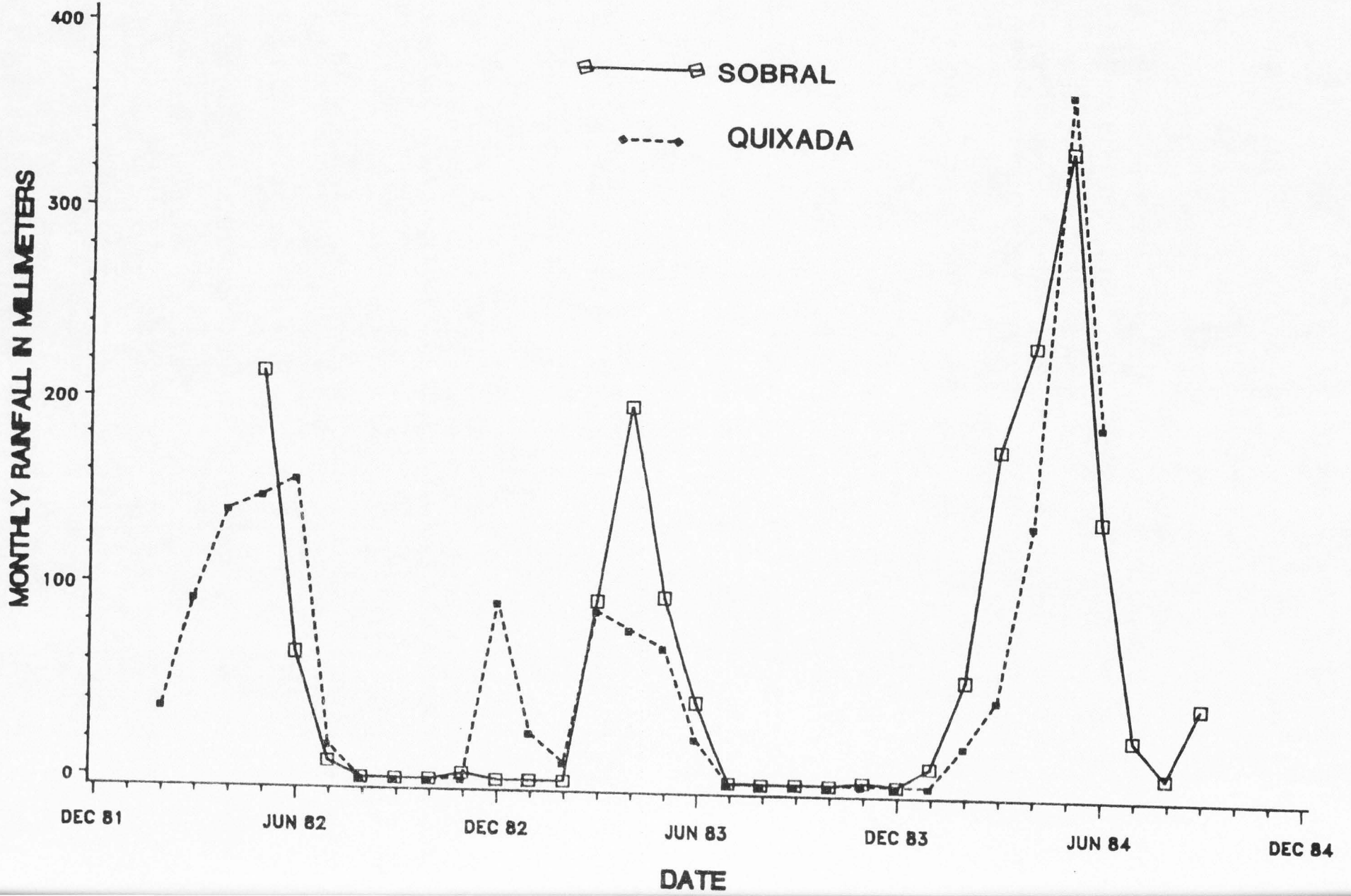
Hardesty, L.H. and T.W. Box, 1982. Preparing women for international service: a case study experience. Proc. Women in Natural Resources: an International Perspective, pages 11-27.

* presentations


SOBRAL
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Percent water (by weight) during 1983 abcission period on Sobral plots cleared in May 1983. (30 cm. depth)

Date	Soil	rep 1 PL	rep 2 PE 1	rep 3 PE 2	mean	variance
4-13-83		-	-	-	-	-
5-03-83		-	-	-	-	-
6-03-83		6.53	10.17	8.75	8.48	1.83
6-29-83		6.17	10.90	6.54	7.87	2.63
7-19-83		3.79	10.46	5.78	6.67	3.42
8-10-83		3.70	10.48	9.48	7.88	3.66
8-30-83		2.79	11.21	8.35	7.45	4.28
10-04-83		8.33	9.41	-	8.87	.76
11-01-83		3.71	10.18	7.09	6.99	3.23
11-29-83		8.12	7.52	7.80	7.81	.30
12-22-83		4.93	6.82	7.64	6.46	1.39

Soil mapping symbols indicate the following:

PL - Planosolo solodico - weakly textured sandy/clay phase, imperfectly drained, relatively flat topography.

PE1 - Podzolico vermelho-amarelho eutrophico - weakly textured sandy/clay phase, moderately to well drained, gently rolling topography.

PE2 - Podzolico vermelho-amarelho eutrophico - weakly textured clay or gravelly clay, moderately to well drained, stoney surface, gently rolling to rolling topography.

PE4 - Podzolico vermelho-amarelho eutrophico - weakly textured clay phase, well to moderately drained, gently rolling topography.

Percent water (by weight) during 1983 abcission period on uncleared caatinga plots in Sobral. (30 cm. depth)

Date	Soil	rep 1 PE 1	rep 2 PE 2	rep 3 PE 4	mean	variance
4-13-83		19.62	15.13	25.85	20.20	5.38
5-03-83		16.34	10.24	5.08	10.55	5.63
6-03-83		16.47	7.20	7.36	10.34	5.31
6-29-83		11.18	8.64	14.22	11.35	2.79
7-19-83		12.67	6.17	7.23	8.69	3.49
8-10-83		2.46	7.02	10.09	6.52	3.84
8-30-83		6.60	5.03	11.01	7.55	3.10
10-04-83		5.82	6.58	6.57	6.32	.05
11-01-83		15.37	11.22	8.23	11.61	3.59
11-29-83		10.83	7.80	9.00	9.21	1.53
12-22-83		10.84	10.10	13.25	11.40	1.65

Soil mapping symbols indicate the following:

PL - Planosolo solodico - weakly textured sandy/clay phase, imperfectly drained, relatively flat topography.

PE1 - Podzolico vermelho-amarelho eutrophico - weakly textured sandy/clay phase, moderately to well drained, gently rolling topography.

PE2 - Podzolico vermelho-amarelho eutrophico - weakly textured clay or gravelly clay, moderately to well drained, stoney surface, gently rolling to rolling topography.

PE4 - Podzolico vermelho-amarelho eutrophico - weakly textured clay phase, well to moderately drained, gently rolling topography.

Regression models used to estimate
coppice biomass production, Quixada 1983

Species and treatment			Regression equation	r^2
Jurema preta				
early dry season				
- leaf	Y	=	702.274 - 1.713 H + .176 D1 - .674 D2	.227
- stem	Y	=	-1561.414 - 8.689 H - 4.566 D1 + 31.805 D2	.836
mid-dry season				
- leaf	Y	=	-625.078 + 15.092 H - 3.916 D1 - 1.813 D2	.926
- stem	Y	=	-2658.041 + 56.157 H - 20.834 D1 + 3.914 D2	.901
early wet season				
- leaf	Y	=	952.892 - 11.217 H + 4.496 D1 - .4106 D2	.955
- stem	lnY	=	6.857 - 1.917 lnH + 1.735 lnD1 + .050 lnD2	.906
Marmeliero				
early dry season				
- stem	Y	=	-80.289 + .274 H + .494 D1 + 2.402 D2	.652
mid-dry season				
- stem	lnY	=	-10.535 + 2.651 lnH - .806 lnD1 + 1.498 lnD2	.906
early wet season				
- stem	Y	=	-56.992 - .766 H - 1.861 D1 + 7.648 D2	.809
Catingueira				
early dry season				
- stem	Y	=	-546.296 + 9.310 H - 4.423 D1 + 3.665 D2	.944
mid-dry season				
- stem	lnY	=	-1.619 - 1.322 lnH - 1.123 lnD1 + 4.059 lnD2	.990
early wet season				
- stem	Y	=	-3.688 + .0002 V	.976

Species and treatment	Regression equation	r^2
Sabia		
early dry season		
- stem	$\ln Y = -11.702 - .533 \ln H + 1.780 \ln D1 + 2.142 \ln D2$	.990
mid-dry season		
- stem	$\ln Y = .062 + 9.146 \ln H - 3.179 \ln D1 - 4.590$	.996
early wet season		
- stem	$\ln Y = -10.852 + 1.057 \ln H + 1.157 \ln D1 + 1.114 \ln D2$	.880

SDW = stem dry weight in grams

$$V = \cdot \frac{D1}{2} \cdot \frac{D2}{2} \cdot H$$

H = height of coppice clump in centimeters

D1 = longest diameter of coppice clump in centimeters

D2 = diameter perpendicular to D1

ln = natural logarithm

Regression models used to estimate
coppice biomass production, Sobral 1983

Species and treatment			Regression equation	r^2
Catingueira				
early dry season				
- leaf	Y	=	3.541 + .906 SDW	.804
- stem	Y	=	84.311 + .0002 V	.819
mid-dry season				
- leaf	lnY	=	-7.418 + .526 lnH + 1.479 lnD1 + .739 lnD2	.947
- stem	lnY	=	-10.094 + 1.169 lnH + 1.780 lnD1 + .345 lnD2	.972
early wet season				
- leaf	lnY	=	-2.717 - .741 lnH - 1.384 lnD1 + 3.996 in D2	.987
- stem	lnY	=	-6.681 + 1.553 lnH + .763 lnD1 + .261 lnD2	.917
Marmeleiro				
early dry season				
- leaf	Y	=	-56.765 + .840 SDW	.831
- stem			#	
mid-dry season				
- leaf			#	
- stem	Y	=	180.644 - .00002 V	.923
early wet season				
- leaf	Y	=	32.727 + 1.032 SDW	.983
- stem	Y	=	-41.858 + .0004 V	.905
Pau Branco				
early dry season				
- leaf	Y	=	44.791 + .486 SDW	.937
- stem	Y	=	-2252.622 + 3.752 H + 7.933 D1 + 8.255 D2	.620
mid-dry season				
- leaf	lnY	=	-2.624 - .111 lnH + .521 lnD1 + 1.364 lnD2	.727
- stem	lnY	=	-11.626 + 2.071 lnH - 1.459 lhD1 + 3.082 lnD2	.894
early wet season				
- leaf	Y	=	28.523 + .706 SDW	.949
- stem	lnY	=	-9.423 - .381 lnH + 2.505 lnD1 + 1.255 lnD2	.936

Species and treatment			Regression equation	r^2
Sabia				
early dry season				
- leaf	Y	=	13.814 + .568 SDW	.863
- stem	lnY	=	-25.220 + 5.957 lnH + .104 lnD1 + .254 lnD2	.857
mid-dry season				
- leaf	Y	=	34.868 + .596 SDW	.784
- stem	Y	=	-438.548 - 1.118 H + 4.946 D1 + .459 D2	.748
early wet season				
- leaf	Y	=	1.419 + .851 SDW	.854
- stem	Y	=	-9.270 + .0001 V	.942

SDW = stem dry weight in grams

$$V = \cdot \frac{D1}{2} \cdot \frac{D2}{2} \cdot H$$

H = height of coppice clump in centimeters

D1 = longest diameter of coppice clump in centimeters

D2 = diameter perpendicular to D1

ln = natural logarithm

= insufficient data available